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تحليل إحصائي لأداء أكوام إسمنت بورتلاند المحتوي مخلفات سيراميك زجاجية

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خلاصة

الهدف من هذه الدراسة هو فحص اعادة استخدام مخلفات صناعات البلاط كبديل لمادة البوزلان الطبيعية (NP) تم فحص الخواص الكيميائية والفيزيائية لخليط ثنائي من إسمنت بورتلاند ومخلفات سيراميك زجاجي. وتم قياس معامل القوة بإضافة كميات من مخلفات السيراميك بنسب وزنية بنسبين هي:

(40٪، 30، 20، 10، 5) ولمدد معالجة هي: 90، 56، 28، 7، 2 يوم.

أظهرت النتائج أن توقيت الإعدادات النهائية لمعجون الإسمنت تم تسريعها عندما استبدلت مادة البوزلان الطبيعية بإضافة المخلفات وظهرت قيم جيدة لقوة الضغط لنسبة مخلفات أقل من 15٪. لوحظ انخفاض في قوة الضغط عند زيادة نسبة المخلفات. النتائج الاحصائية أظهرت أن مخلفات السيراميك الزجاجية بديل رئيسي لمواد الإسمنت التكميلية. استخدام نسبة أقل من 15٪ من مخلفات السيراميك يمكن أن يكون بديلا لمادة البوزلان الطبيعية. وأظهرت النتائج زيادة في قوة الضغط مع زيادة نسبة المخلفات حتى 10٪ مقارنة مع العينات التي استخدمت كمرجع.

Statistical Analysis of the Effect of Portland Cement Mortars' Performance Containing Glazed Ceramic Waste

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ABSTRACT

The purpose of this study is to investigate the reusability of waste from tile manufacturing as an alternative material to natural pozzolan (NP) - trass.

Chemical and physical analyses of the binary components of Portland Cement (PC42.5N), NP, and Glazed Ceramic Waste (GCW) were conducted. The strength values of PC42.5N were measured by adding trass and GCW at various weight ratios by cement weight (5, 10, 20, 30, 40%) to curing periods of 2, 7, 28, 56, and 90 days. The results show that the final setting time of cement pastes is generally accelerated when NP was replaced with cement. Based on the test results, there are good compressive strength values with less than 15% concentrations of waste materials. A decrease in strength was observed at increased concentrations of waste materials. Statistical results show that GCW is an alternative to trass as a supplementary cementing material (SCM) with PC42.5N. Using less than 15% of GCW as an additive was observed to be an alternative to trass. The results also indicated that there is an increase in compressive strength when up to 10% of NP is added, compared with that of the control concrete and with trass.

Keywords: Statistical Analysis; Reusability of Waste; Glazed Ceramic Waste; Fischer Distribution; Analysis of Variance (ANOVA).

INTRODUCTION

Waste materials can be used as a substitute for cement (Hazra & Krinaswamy, 1987; Hwang & Wu, 1989; Ozer & Hulusi, *2004*; Shannag *et al.*, 1995; Zhang & Malhotra, 1996). These materials are called supplementary cementing materials (SCM). Natural SCM are true pozzolans and volcanic tuffs.

Artificial SCM are siliceous by-products such as fly ash, limestone powder and condensed silica fume (Ezziane *et al.*, 2007; Felekoglu *et al.*, 2006; Ozer & Hulusi, 2004; Ramyar & Inan, 2007).

According to ASTM C595 (1998), a pozzolan is defined as "a siliceous or siliceous-aluminous material chemically reacting with calcium hydroxide to form compounds possessing cementitious properties (pozzolanic activity)". Thus, a pozzolanic material requires $Ca(OH)_2$ in order to form strengthened products, whereas a cementitious material contains quantities of CaO and can exhibit a self-cementitious (hydraulic) activity. Usually, the CaO content of a cementitious material is insufficient to react with all the pozzolanic compounds. Thus, it also exhibits pozzolanic activity (pozzolanic and cementitious materials). However, all these materials are often used in combination with Portland Cement (PC) which contains the $Ca\ (OH)_2$ essential for their activation, from its hydration.

In Turkey, one of the most important industries that cause CO_2 emission is cement and concrete production. Producing cement uses a great deal of energy, so finding a waste product that can substitute for cement makes good environmental sense. It is also necessary to decrease clinker production and utilization, which is possible by using SCM.

In the last 30 years, many countries including European countries agreed to reduce the emission of CO_2 by the end of 20th century according to the Kyoto protocol but were compelled to lower their quality criteria so that waste materials could be used as a substitute for cement (Ozer & Hulusi, 2004).

After the invention of PC, SCM were used to design concrete mixtures with optimum cement content. As a practical matter, the use of SCM can provide major economical and ecological benefits because the use of these materials permits a reduction in the amount of PC in the mixture. Blending SCM with PC leads to lower permeability and higher strength, durability and chemical resistance, and because of the good cost-quality balance of SCM, there has been a growing trend towards their use in concrete materials (Colak, 2002; Hazra & Krinaswamy, 1987; Hwang & Wu, 1989; Ozer & Hulusi, 2004; Shannag *et al.*, 1995; Shannag, 2000; Zhang & Malhotra, 1996).

While the use of SCM often provides higher strengths for concrete at later stages, their strength in the early phases is deficient in contrast to pure PC. It is therefore a primary objective of the present study to provide an improved GCW which combines with concrete products to increase the early strength of the concrete-SCM product. GCW can be used as an alternative additive with cement paste to significantly increase the engineering strength. GCW is environmentally friendly because it reduces the consumption of cement and NP.

The basic strategy of the present investigation is to test the influence of variable percentages of GCW cement on strength. However, design standards, including mix proportioning and information on the structural design of GCW concrete, have not been established. This paper focuses on an attempt to predict the compressive strength of GCW concrete by creating a prediction model that will be a useful tool for the mix proportioning of GCW concrete in Turkey. Another objective of the present study is to identify improved SCM which are both safe and economical to use.

The replacement of PC42.5N by 5-10% of NP in the presence of a fixed quantity of GCW improves the bending strength of the specimens after 56 days of curing compared with control specimens (Papadakis & Tsimas, 2002). It was observed that fine particles of pozzolanic materials increased the strength. By taking SEM photographs, it was determined that the GCW particles were smaller than the PC42.5N particles.

At the end of the experiments, a statistical inference study was performed to improve the experimental models. It was proved by statistical inference that the values of the laboratory trials are very close to each other for trass and GCW.

Compressive strength modeling was carried out using the same GCW/trass ratio in the literature (Altin *et al.*, 2008; Terro & Sawan, 1998).

EXPERIMENTS

Glazed Ceramic Waste (GCW-tiles), trass and PC42.5N were investigated as additives in this study.

Table 1. Chemical analysis of samples used

	Material		
	PC42.5N	**Trass**	**GCW**
Silicon dioxide, SiO_2	20.07	65.33	56.9
Aluminum oxide, Al_2O_3	4.43	15.23	17.5
Ferric oxide, Fe_2O_3	3.56	3.35	0.39
Calcium oxide, CaO	63.91	5.07	5.24
Magnesium oxide, MgO	1.09	0.7	2.17
Sulfur trioxide, SO_3	2.62	0.65	3.83
Sodium oxide, Na_2O	0.17	3.21	0.92
Potassium oxide, K_2O	0.65	1.74	0.43

Cont. Table 1. Chemical analysis of samples used

	Material		
	PC42.5N	**Trass**	**GCW**
Phosphorus pentoxide P_2O_5	0.04	-	0.1
Titanium dioxide, TiO_2	0.27	-	0.26
Magnesium oxide, MnO	-	-	0.04
Chrome oxide, Cr_2O	-	-	0.07
Ignition loss, IL	3.21	6.14	7.9
Specisurface (m^2/kg)	352	921	3200

Sample preparation and method

The experiments were conducted with additive content varying from 5 to 20% and having curing periods of 2, 7, 28, 56, and 90 days (Altin *et al.*, 2008).

Duration of setting time was performed at ambient temperature conditions of 20 ± 2°C and 50 humidity. To determine its viscosity the clay (300 grams of cement) was placed into a metal vessel of 25cm diameter and of 8cm depth. Tap water as much as 25 of cement was added and the viscosity was measured by a Vicat Instrument. A vibrating sieve machine of 90-200 μm was used to measure particle size. Le Chatelier Bottle was used to measure density. A Blaine Instrument was used to determine the specific surface. Water, to be used for the strength test, was kept at an ambient temperature for at least 24 hours. The amount of trass or GCW added to the cement samples was between 5% and 20% (per weight of cement). For the strength tests, 225ml of water was put into the sample vessel and 450gr of sample cement was added. One minute later 1350gr of sand was added in less than one minute. After the automatic program of the instrument was completed, half of the mixture was poured into the mould which was placed on the shock table. The content was agitated for one minute then the other half of the mixture was also added to the mould and the agitation continued. The mould was covered with a glass plate and placed in a humid cabinet. After waiting for 24 hours, the mould was removed from the cabinet and placed in a constant temperature bath at 20 ± 1°C and kept in a chamber where the humidity level was kept at a minimum of 90% for 20-24 hours. The sample was removed from the mould after 2, 7, 28, 56, and 90 days and relative strength levels were measured. Five samples for each set of the experiment were prepared and measured. The pressure strengths at 2, 7, 28, 56, and 90 days were measured (4 trials were done for each test). Chemical analysis was done on an Oxford Labx3000 X Spectrum Spectrophotometer. Samples were dried in an oven and were sieved with a 40-90 μm sieve. Dried samples were ground by a Linatex mill for 55 minutes then physical mechanical experiments were carried out according to the TS 24 standard. SEM photographs of the samples were taken by a JSM-

5410LV Electron Microscope Scanner. For the SEM measurements small pieces were taken from the 2, 7, 28, 56 and 90 day samples in the moulds and ground to a powder, which were then dried at 100°C in a drying oven. The dried powder was placed on an adhesive carbon strip and compressed.

TEST RESULTS AND DISCUSSION

Originally, GCW is in a mud-state when leaving the factory. Later, these were dried under atmospheric conditions. Before being added to the PC42.5N, the GCW was additionally dried in the drying oven, prior to the strength tests. The composition of the PC42.5N and trass used in the experiments is given in Table 1.

As additives, the crystalline structure of the trass and GCW enables them to decrease the strength. An XRD analysis of the GCW used in the present work shows crystalline SiO_2(quartz), zircon($ZrSi_4$), albit [(Na, Ca) Al(Si, $Al)_3O_8]_7$, Chlorite[(Mg, Fe, $Al)_3$(Si, $Al)_6$ $O_{10}(OH)_8]_7$ and Illit[KNaMgFeAl SiO H_2O]. NP trass includes crystalline quartz, albit, illit, clinoptilolite and calcite. Since the granular size of the GCW is much smaller and more uniform compared to that of the trass, the GCW causes less decrease in the strength of PC42.5N than the trass.

The pozzolanic reaction between NP and CaOH occurs after the lime and C_2S in the cement begin to hydrate. At the early stage of curing, substituting 20% of the NP in the PC42.5N mixture gives a slightly lower compressive strength than the reference of PC42.5N.

A trend of increasing compressive strength is observed for both sets of specimens during the curing time. The compressive strength of the pozzolanic cement specimens (up to 10%) was almost equal to those of the control specimens, at 56 and 90 days. The compressive strength in both specimens increased over time, but the increasing rate of the compressive strength of the pozzolan-containing specimens was lower than that of the control specimens for times greater than 28 days. The difference between the GCW and control samples was small in comparison with the benefits of using the GCW. Moreover, adding waste tile into cement reduces cost.

On the basis of these findings, it can be suggested that the GCW cement would be a good substitute for the PC42.5N in cement-based products without any considerable decrease in compressive strength. Substituting about 10% of PC42.5N with GCW will increase the compressive strength. Waste tiles can be added to cement, up to a weight ratio of 15%.

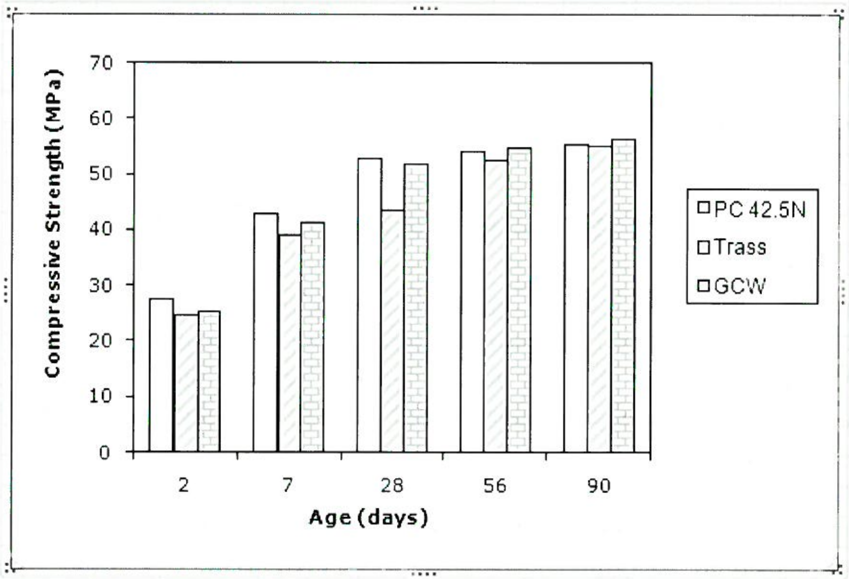


Fig.1. The compressive strength of cement paste with 5% trass/GCW

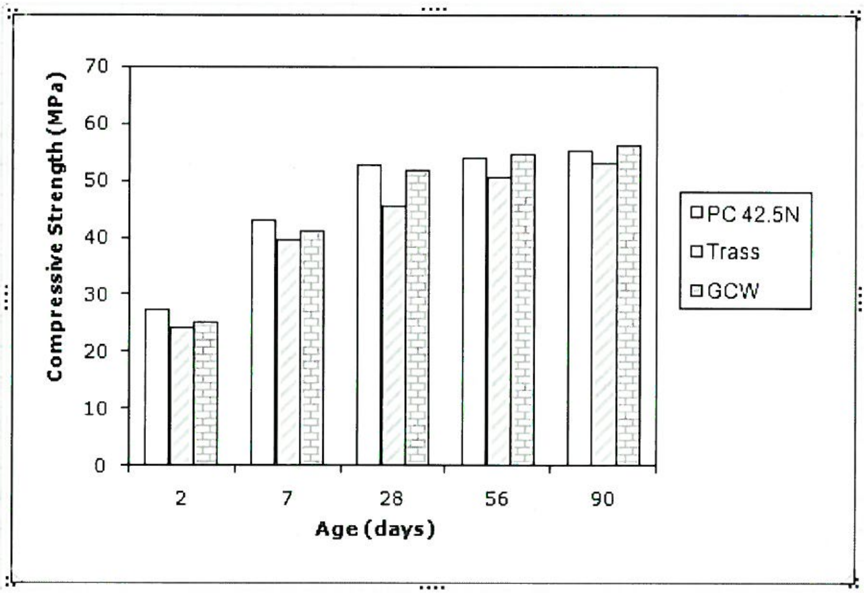


Fig. 2. The compressive strength of cement paste with 10% trass/GCW

It was found that all pozzolan-cement samples which were cured for 7 days revealed lower compressive strength and stiffness compared with the GCW-cement stabilized samples. The difference in strength was -3.95, -4.46, -1.74, and

3.75% for 5, 10, 15, and 20% NP, respectively. The reason for the above-reported differences is related to the retarding action of the GCW on the pozzolanic reactions and consequently on the cement hardness. The strength values of the GCW-cement stabilized samples which were cured for 28 days were higher than the values of the cement samples treated only with pozzolan.

In the case of 5% GCW addition, the increment of strength was 1% while with larger amounts of cement this increment was almost stable between 1 and 2% (Figure 1 and Figure 2). Consolidation characteristics improved greatly as the cement content was increased. GCW additive of up to 10 percent had only a marginal effect on this improvement.

When SCM replace cement, the strength is reduced at first, but as time precedes this reduction is gradually eliminated. After 90 days, for the GCW specimens of up to 10%, the strength becomes higher than that of the control specimens. This ultimate improvement is due to the higher active silica content of the GCW in comparison with the cement.

The compressive strength of different batches at different ages is shown in Table 2a-b. The results of the control specimens without any supplementary material are also shown. At 2 days of curing time, the compressive strength of the specimens containing supplementary materials was less than that of the control for all batches. Many researchers have reported that the appearance of the strength was slowed in the early curing period by adding NP, because the overall pozzolanic reaction was slow (Shannag *et al.*, 1995; Shannag, 2000). However, the strength was increased, exceeding the reaction by a large amount, within a few weeks.

In Table 2b, it is observed that the replacement of up to 15% PC42.5N by GCW resulted in an increase in the 56- and 90-day strengths, relative to the strength of the specimen containing no supplementary material.

Table 2a. Decrease in strength of PC42.5N upon addition of trass.

Waste Ratio (%)	**Decrease in strength with trass (kgf/cm^2 and %)**									
	2 days		**7 days**		**28 days**		**56 days**		**90 days**	
	kgf/cm^2	**%**	**kgf/cm^2**	**%**	**kgf/cm^2**	**%**	**kgf/cm^2**	**%**	**kgf/cm^2**	**%**
5	2.65	9.65	3.73	8.70	9.1	17.27	1.5	2.78	0	0.00
10	3.24	0.12	3.05	7.12	6.9	13.09	3.4	6.30	1.9	3.44
15	5	0.18	5.1	11.90	8.1	15.37	4.6	8.52	3.4	6.16
20	6.67	0.24	7.16	16.71	14.6	27.70	4.6	8.52	3.4	6.16

Table 2b. Decrease in strength of PC42.5N upon addition of GCW

Waste Ratio (%)	Decrease in strength with GCW (kgf/cm^2 and %)									
	2 days		7 days		28 days		56 days		90 days	
	kgf/cm^2	%	kgf/cm^2	%	kgf/cm^2	%	kgf/cm^2	%	kgf/cm^2	%
5	1.67	6.08	1.38	3.22	-0.45	-0.85	-0.2	-0.37	-0.6	-1.09
10	2.16	0.08	1.57	3.66	0.63	1.20	-0.8	-1.48	-1.1	-1.99
15	4.61	0.17	5.3	12.37	8.06	15.29	2.7	5.00	3.7	6.70
20	7.45	0.27	6.18	14.42	14.55	27.61	9.9	18.33	11	19.93

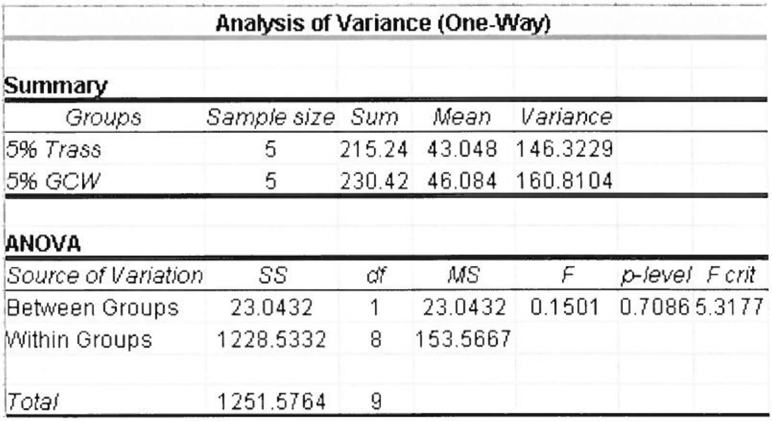
Further replacement of a surplus of 10% NP resulted in a slight decrease in the compressive strength (Table 2a). It is interesting to see that among all the mixes made, the one containing 10% GCW achieved the highest strength after 90 days. The increase in the strength of specimens due to the replacement of the GCW can be attributed to improve bridging between the particles. On the other hand, the observed decrease in the strength of the specimens due to the replacement of the PC42.5N by the GCW can be explained by the fact that a larger replacement (more than 10%) leads to a surplus of the small-sized particles, which begins to move the PC42.5N grains apart, causing unpacking of the system and thus leading to a considerable decrease in the strength of the system (Shannag, 2000).

In Table 4, the values of strength after 2, 7, 28, 56, and 90 days for trass or GCW are presented. In view of these data, the GCW, when added to the PC42.5N at concentrations of 5% and 10%, causes the least decrease in strength.

Some statistical inferences

To verify statistically the influence of the factors studied in the experimental program as well as their interaction we performed an analysis of variance. The use of variance analysis is based on the relationship between the variability of the averages between the groups and the variability of the observations within the groups as well as in the Fischer distribution (F) with a significance level á = 0.05. If F is less than 0.05, the factor or the interaction between the factors that is being evaluated is considered significant, that is, it has an effect on the response.

Table 3a. Analysis of Variance(ANOVA) for 5% trass or GCW additive



Analysis of Variance (One-Way)

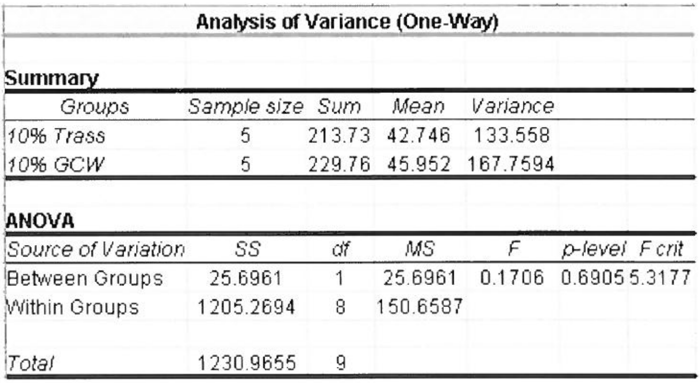
Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
5% Trass	5	215.24	43.048	146.3229
5% GCW	5	230.42	46.084	160.8104

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	23.0432	1	23.0432	0.1501	0.7086	5.3177
Within Groups	1228.5332	8	153.5667			
Total	1251.5764	9				

Table 3b. Analysis of Variance for 10% trass or GCW additive



Analysis of Variance (One-Way)

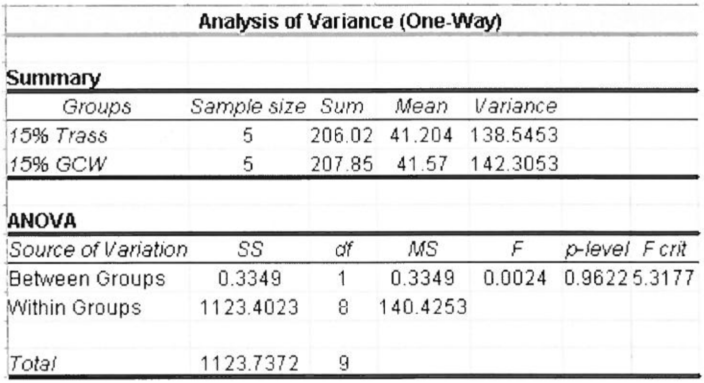
Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
10% Trass	5	213.73	42.746	133.558
10% GCW	5	229.76	45.952	167.7594

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	25.6961	1	25.6961	0.1706	0.6905	5.3177
Within Groups	1205.2694	8	150.6587			
Total	1230.9655	9				

Table 3c. Analysis of Variance for 15% trass or GCW additive



Analysis of Variance (One-Way)

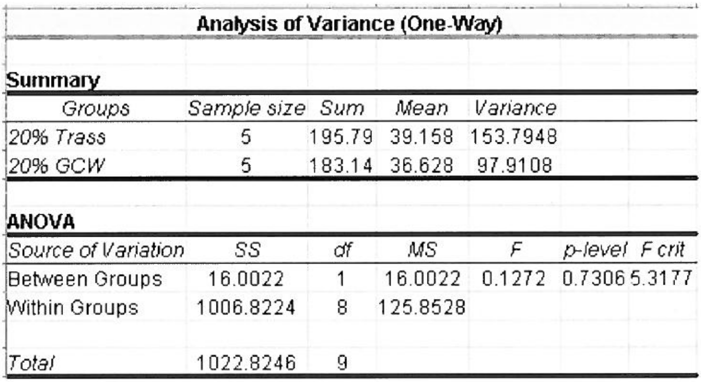
Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
15% Trass	5	206.02	41.204	138.5453
15% GCW	5	207.85	41.57	142.3053

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	0.3349	1	0.3349	0.0024	0.9622	5.3177
Within Groups	1123.4023	8	140.4253			
Total	1123.7372	9				

Table 3d. Analysis of Variance for 20% trass or GCW additive



Analysis of Variance (One-Way)

Summary

Groups	Sample size	Sum	Mean	Variance
20% Trass	5	195.79	39.158	153.7948
20% GCW	5	183.14	36.628	97.9108

ANOVA

Source of Variation	SS	df	MS	F	p-level	F crit
Between Groups	16.0022	1	16.0022	0.1272	0.7306	5.3177
Within Groups	1006.8224	8	125.8528			
Total	1022.8246	9				

Table 4. Mechanical analysis results of GCW and trass with PC42.5N at different concentrations

		For trass Strength (MPa)					For GCW Strength (MPa)				
	Additive Ratio (%)	**2 Days**	**7 Days**	**28 Days**	**56 Days**	**90 Days**	**2 Days**	**7 Days**	**28 Days**	**56 Days**	**90 Days**
	0	27.46	42.86	52.7	54.0	55.2	27.46	42.86	52.7	54.0	55.2
	100	0	89	0			0	0	0		
	5	24.81	39.13	43.6	52.5	55.2	25.79	41.48	53.15	54.2	55.8
	10	24.22	39.81	45.8	50.6	53.3	25.30	41.29	52.07	54.8	56.3
	15	22.46	37.76	44.6	49.4	51.8	22.85	37.56	44.64	51.3	51.5
	20	20.79	35.70	38.1	49.4	51.8	20.01	36.68	38.15	44.1	44.2
Descripive Statistics	Count	4	4	4	4	4	4	4	4	4	4
	Mean	23.07	38.1	43.025	50.475	53.025	23.4875	39.2525	47.0025	51.1	51.95
	Standard Deviation	1.818	1.813	3.404	1.464	1.613	2.651	2.490	7.010	4.911	5.598
	Standard Error (of Mean)	0.909	0.907	1.702	0.732	0.807	1.326	1.245	3.505	2.455	2.799
	Minimum	20.79	35.7	38.1	49.4	51.8	20.01	36.68	38.15	44.1	44.2
	Maximum	24.81	39.81	45.8	52.5	55.2	25.79	41.48	53.15	54.8	56.3
	Range	4.02	4.11	7.7	3.1	3.4000	5.78	4.8	15	10.7	12.1
	Sum	92.28	152.4	172.1	201.9	212.1	93.95	157.01	188.01	204.4	207.8
	Sum Standard Error	3.637	3.626	6.809	2.928	3.227	5.302	4.979	14.02	9.821	11.196
	Variance	3.3068	3.2869	11.589	2.1425	2.6025	7.0286	6.1984	49.139	24.113	31.33666

When pozzolanic materials are used to replace cement at a high percent, early strengths may be reduced. However, these early strengths can be increased by substituting the pozzolanic material for the cement at a high percent at a ratio of one to one for the cement replaced, provided that the water content is not increased excessively. The contribution of the pozzolanic strength development occurs some time after seven days of hydration (Mehta, 1998).

Due to higher contents of C_3A in the NP-cement, exposure to the sulfate solution led to greater expansion. The expansion occurred due to formation of high volume products in the matrix, such as gypsum and ettringite. Therefore the use of the Portland NP-containing cement products in a sulfate environment cannot be supported especially at the early ages of curing, such as 14 and 28 days.

With a replacement level of up to 15%, the general effect of the NP was to retard the initial setting time. However, increasing the replacement of PC42.5N by NP or GCW, results in a decrease in the final setting time compared to the control cement. When compared to the control concrete, substitution of up to 15% GCW by PC increases the compressive strength of the specimens after 28 days of curing. GCW can also be directly added to PC42.5N, without grinding. When GCW is added to PC42.5N at concentration levels of 5-10%, the results of the strength tests after 2, 7, 28, 56, and 90 days were higher than those obtained by the addition of NP.

It has been demonstrated from examination of the test results in this study that the strength of a concrete mixture made with GCW or NP can be related to the strength of a PC42.5N control mixture. Waste tiles can be added into cement up to a weight ratio of 20%. Adding waste tiles into cement reduces cost. In addition, they can be employed as the pozzolanic component of general purpose Portland pozzolanic cements in an environmentally friendly way. Thus, disposal to landfill of the waste tiles is avoided, and they can be employed in cement manufacture as extenders, thereby saving on the high energy costs of Portland clinker production. However, adding waste tiles to cement also results in prolonged setting time and causes reduction in the workability of the pastes, mortar and concrete, beyond a 20% replacement.

CONCLUSIONS

The conclusions from the compression tests are described below.

The higher the percentage of cement added, the higher the increase in strength and stiffness of the concrete.

Development of strength and stiffness with a short curing time (2, 7 days) is delayed significantly because of SCM addition, while with a long curing time (56 days) the engineering parameters are increased considerably.

While it is stronger and more durable in the end, it takes more time for pozzolans to gain strength than it does for PC42.5N. For most construction purposes, high early strength is very desirable because it allows quicker finishing of slabs and earlier removal of forms. Mixes with 5% to 15% SCM, and somewhat higher percentages of GCW, can be used in home-building with only modest slowing in strength. Higher percentages can be used in footings, where high early strength is typically not important.

NP and GCW cement were used in this study: their properties were compared with those of Portland type II cement. By substituting about 10% of the PC42.5N with NP, the compressive strengths of these specimens were only slightly affected (actually less than 5%).

These results suggest that the NP-containing concrete could be durable beyond these ages. The lower reactivity of the NP caused weaker performance of the NP-cement than PC42.5N in the freeze and thaw and sulfate expansion tests.

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استخدام التحليل المبني على عوامل متعددة لتقييم أداء محطات انتاج الطاقة من الرياح

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خلاصة

تقدم هذه الدراسة تحليل القرار متعدد المعايير (mcda) لتقييم بدائل انتاج طاقة الرياح التي تقع في منطقة مرمره في تركيا. الهدف الرئيسي من هذه الدراسة هو إدراج معايير تحديد الأولويات لتقييم مختلف محطات طاقة الرياح. لتحقيق هذا الهدف تم اعتماد نموذج القرار الهرمي المبني على عوامل متعددة لاتخاذ القرار باستخدام نهج عمليات تحليل هرمي ضبابي (FAHP). تم استخدام التحكيم الكمي للخبراء وتم تقييم كافة البدائل وفق معايير اقتصادية وتقنية وبيئية. في الطريقة المقترحة تم اعطاء وزن لكل من عوامل التقييم عن طريق تحليل أداء المصفوفات (AHP). وأخيرا تم اختيار أفضل مجموعة إنتاج طاقة من الريح في المنطقة التي تم دراستها.