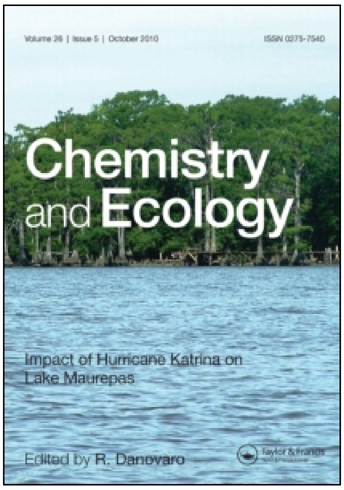

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THE REUSE OF URBAN AND INDUSTRIAL WASTE IN TAI-LIN-PU RECLAMATION PROJECT, TAIWAN

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This study introduces the principles of KMG's (Kaoshiung Municipal Government) dealing with the non-poisonous urban and industrial waste through reclamation of shore land in reinforcing a sense of coastal protection and land development in Tai-Lin-Pu coastal area, southern Taiwan.

Through a series of experimental studies, we found that substitutes of coarse aggregate with a broad spectrum of integrating slag powder, fly ash, and cementitious material can be obtained with a benefit up to 80% saving of cement. The integrated aggregates from the non-poisonous industrial wastes were subsequently made into armour units and used in the field tests at Tai-Lin-Pu coastal area, where the shorelines are seriously eroded. After being subjected to several severe typhoon advents, the results showed that the waste-made units used as the protection breakwater, together with construction wastes and excavated soil as the filling material, prove to be an effective practice in utilizing recycled urban waste to reclaim erosive shore lands. Moreover, this study also demonstrates that through detailed analysis of the waste characteristics, scrap material could be turned into valuable construction aggregates, and highlights the value of non-poisonous urban and industrial waste as a alternative resource for the shore protection engineering.

KEY WORDS : reclamation, slag, fly ash, Tai-Lin-Pu coastal area, southern Taiwan

INTRODUCTION

The city of Kaoshiung is located in the southwestern Taiwan, R.O.C., with a shoreline facing Taiwan Strait. It has been the major industrial centre in southern Taiwan in the past due to its geographical conditions and the commercial operation of Kaohsiung Port, which is ranked among the top five in the world. The enactment as a Municipal City in 1979 helped to speed up the development of the city, especially in construction engineering, but in the meanwhile construction wastes have increased at a surprising rate. As a result, finding suitable disposal sites to accommodate these wastes becomes more difficult due to arising awareness of the environmental protection. This has imposed a significant burden on the City Government. Therefore, in order not to pollute the environment and blemish the City by uncontrolled disposal, the City Government in 1980 initiated a project of storing the construction waste material and excavated soil at Tai-Lin-Pu costal area to reduce the burden of waste disposal (BEP/KC, 1989).

In the beginning, the process of disposing the construction wastes was simply by dumping the wastes into the coastal zone. Being directly subjected to north-bound wave and tide action, much of the disposed wastes eroded away and accumulated in the nearby northern regions. Meanwhile, the regional sea water deteriorated and became yellowish and very dirty, which not only seriously damaged the marine environment but also affected the intake water quality of a near-by power plant. Therefore, a more controlled disposal site with the potential of reusing some waste was proposed to solve this problem and, hopefully, to establish a model for future applications on Taiwan Island.

Based on previous studies (Chang *et al.*, 1991), blast furnace slag powder and fly ash had been recommended as alternative substitutes for construction aggregates, which are also abundant in this area and need to be disposed of properly. For this study, we first selected slag powder and fly ash from two regional major industries, China Steel Corporation and Taiwan Power Company, for evaluation of their applicability. Finally, we present preliminary results of the Tai-Lin-Pu Reclamation Project, which utilizes the construction wastes and excavated soils as the filling material and the industrial-waste-made armour unit as the protection breakwaters.

EXPERIMENTS

Experimental studies were aimed at determining the strength of the industrial waste-made substitute of concrete material for future designs. The study included laboratory and field tests on several characteristics of the substitute material and will be detailed in the following sections.

A series of tests on the strength of concrete made with different combinations of slag, slag powder, and fly ash with cement (see Cornell, 1986; Snee, 1971) were conducted in the laboratory of Civil Engineering, National Taiwan University. In the tests, the slag powder together with fly ash were designated as an alternative substitute cement while the coarse slags were used as an alternative aggregate substitute. Thus, the reused industrial wastes were cast into either cylindrical or rectangular units to test three variables, i.e. aggregate type, cement/water ratio, and replacement percentage of slag powder and fly ash. The waste-made specimens were all cured according to ASTM C684 with total relative humidity R.H.·= 100%, at 23°C for one day and then at 100°C for another 3.5 hours. The design conditions for each variable are listed in Table I.

The strength test was aimed at determining the suitable ratio of slag powder and fly ash in replacing the cement at different values of cement/water ratio. Here, the waste-made concrete was cast into cylindrical units 10 cm in diameter and 20 cm in height. The test conditions with different combinations of the variables in Table I are listed in Table II and the results recorded for further analysis.

Deformation tests were designed to study the creep and shrinkage of the concrete specimens made with substitute aggregates. The substitutes employed were raw slag

Table I Major variables on laboratory concrete test

Coarse Aggregate Classification	W/C Ratio	Slag Powder + Flyash*	Curing Condition
Clean Air-cooled Coarse Slag	0.59	0 + 0	23°C, R.H. = 100%
Ordinary Coarse Aggregate	0.65	65 + 0	**
Raw Coarse Slag	0.71	80 + 0	
		65 + 15	
		50 + 30	

* Follows ASTM C684 test method cured under 23°C, R.H. = 100%, for one day, then cured at 100°C for 3 1/2 hrs. W/C = water:concrete ratio

Table II Test conditions with different combinations of variables: content (kg) of each m^3 of concrete

Formulation	590PC	595S50	59Ss65	595S80	59Ss65	59Ss80	59Ss65f15	59Ss50f30	65s65	65s80
W/C	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.65	0.65
Water	193	193	193	193	190	190	190	190	193	193
Sand	678	668	665	662	754	751	728	704	692	692
Ordinary aggregate	1127	1127	1127	1127	0	0	0	0	1127	1127
Slag aggregate	0	0	0	0	892.67	892.67	892.67	892.67	0	0
Cement	327	163.5	114.4	65.4	112.7	64.4	64.4	64.4	103.9	55.4
Slag powder	0	163.5	212.6	261.6	209.3	257.6	209.3	161.0	193	237.5
Flyash	0	0	0	0	0	0	48.3	96.6	0	0
Slump (CM)	8.5	13.5	10.5	9.5	13.5	10	13	13	12	13.5
Formulation	65Ss80	65Ss65	65Ss65f15	65Ss50f30	71Ss65	71Ss80	71Ss65f15	71Ss50f30	71s65	
W/C	0.65	0.65	0.65	0.65	0.71	0.71	0.71	0.71	0.71	
Water	190	190	190	190	190	190	190	190	193	
Sand	778	780	756	731	802	800	780	760	714	
Ordinary aggregate	0	0	0	0	0	0	0	0	1127	
Slag aggregate	892.67	892.67	892.67	892.67	892.67	892.67	892.67	892.67	0	
Cement	58.46	102.3	58.5	58.5	93.7	53.5	53.5	53.5	95.1	
Slag powder	234	190	190	148.5	173.9	214.1	173.9	133.8	176.7	
Flyash	0	0	43.85	89.07	0	0	40.14	80.3	0	
Slump (CM)	10	13.5	13	13	11	11.5	13	13	10	

W/C = water:cement ratio

and cleaned slag, and the results were compared subsequently with the normal construction aggregates.

In creep tests, the concrete specimens were cylindrical with the same dimensions as in strength tests but the test procedures were in accordance with the ASTM C512. In particular, the replacement ratio between slag powder and cement was fixed at 65% with different combinations of the parameters in Table III and all the specimens were cured for 28 days before being put to test.

In shrinkage tests, the specimens were rectangular with dimensions of 7.5 cm × 7.5 cm × 30 cm and were, following ASTM C341, all cured in an environment with a temperature of 23°C and R.H. of 50%. The replacement ratio of slag powder and cement was fixed at 65%, the cement/water ratio were also fixed at 59%, while the three types of aggregate listed in Table I were all used. The test specimens were all dried first and their strain changes were recorded mechanically.

IN-SITU TEST

The results from the laboratory tests were subsequently applied in the field at Tai-Lin-Pu coastal area by conducting studies on the prototype waste-made concrete armour unit. The tests consisted of a strength test, temperature measurement, and strain tests, and will be detailed in the following sections. In addition, test conditions for field tests were selected from the laboratory conditions in Table II which showed more satisfactory results.

The overall and partial distributions of strength in a prototype concrete armour unit were studied by four types of tests as follows:

Following the codes of China National Standard (CNS) 1232 and for each designed test combination, thirty test cylindrical specimens, which have the same dimensions (15 cm diameter, 30 cm height), were cured outdoor in air, fresh water and sea water for a certain period and then subjected to a compression test for comparison of the concrete strength and different ratios of components.

To study the strength distribution at different locations inside the prototype concrete armour units, coring samples were taken from concrete units which had been cured for 7, 28, and 90 days, respectively. The samples were subsequently cut into specimens with 20 cm in height and subjected to compression testing according to CNS 1238 and ASTM C42.

The tests were conducted, following CNS 10732 and ASTM C805, on prototype concrete armour units at several locations. The units were first cured for 7 and 28 days and the results compared later with those from cylindrical compression testing.

This testing was conducted at several locations on both prototype concrete units and rectangular specimens, with dimensions of 10 cm high, 10 cm wide, and 35 cm long, using a portable digital ultrasonic inspection meter. The data from specimens were used for calibrating the results from prototype units.

To study the temperature variations in the prototype concrete units due to the hydrolised reaction of the glue material or the Portland reaction, the temperature change in the units was recorded after the concrete deposition. The measurement was made using the titanium-nickel alloy thermal conductor through the KAYE thermal data acquisition system.

To compare the strain changes in a rectangular specimen with dimensions of 10 cm × 10 cm × 35 cm with the prototype units, several strain gauges were glued on to the test samples immediately after deposition and data were recorded by mechanical meters.

Table III Sea water quality in Tai-Lin-Pu area

Location: T-11

Sampling Time day/time	Ambient temp (°C)	Water temp (°C)	pH	Concentrations* Phenols	Nitrite	Nitrate	Phosphate	DO	BOD	Cu	Cr	Cd	Ni	Pb	Zn	Hg
78.03.02 10:35	21.7	23.0	8.06	138.26	16.87	26.97	43.89	8.99	4.28	7.13	<3.25	<0.50	7.79	2.23	27.38	<0.25
78.04.28 10:26	27.0	26.1	8.16	4.47	12.70	63.07	28.93	8.37	3.32	12.52	<3.25	<0.50	3.47	19.49	5.90	<0.25
78.06.30 10:25	30.8	29.4	7.58	27.29	–	26.52	10.19	8.00	1.76	13.59	<3.25	1.30	2.19	20.24	37.40	0.27
78.08.31 10:30	31.0	32.5	8.47	13.59	1.47	17.60	16.89	–	–	28.11	12.16	51.72	5.97	64.75	68.13	0.89
78.11.03 10.36	27.0	28.5	8.57	–	0.16	29.49	45.14	–	–	4.82	4.78	4.91	4.78	21.31	25.25	1.14
79.01.11 11:10	24.0	23.0	8.23	–	4.06	49.72	14.25	7.25	1.36	17.41	1.07	17.47	<0.4	12.31	10.12	0.36
79.03.01 10:31	18.0	23.0	8.34	–	3.07	45.77	14.25	6.55	2.36	5.48	1.00	2.47	1.70	33.67	20.67	0.78
79.04.26 10:41	25.0	26.0	8.33	10.66	13.61	93.53	40.64	6.19	1.17	3.96	6.68	1.82	2.12	35.72	22.90	1.01
79.06.27 11:27	30.0	33.0	8.25	7.88	4.72	290.83	16.89	6.84	0.49	2.42	7.80	<0.5	1.02	1.56	9.29	1.42
80.10.17 10:24	28.5	25.6	8.31	<1.0	<1.0	19.60	110.70	5.56	0.55	165.10	32.30	<0.5	38.60	19.40	40.70	2.20
81.01.07 10:18	23.4	20.6	8.20	<1.0	32.40	11.00	125.20	6.89	0.89	32.30	10.10	<0.5	2.80	4.40	≤0.5	–

*Concentrations all expressed as ppb, except dissolved oxygen (DO) as ppm

After the placement of the reused waste at the project site, water quality in the near coastal region was monitored continuously at eleven stations to ensure that, in the long term, the waste material will not cause any contamination in the nearby regions. Moreover, during the construction, geo-textiles were also placed behind the breakwater to prevent the loss of the filled material.

RESULTS AND DISCUSSION

With the same water/cement ratio of 0.59 and air-cooled slags as the aggregate, the concrete strength with a replacement ratio (slag/cement) of 65% approaches that of pure cement (OPEC) as the curing time of samples increases.

For a substitute cement made by adding only slag powder, concrete strength grew more rapidly than that of the OPEC cement after the first seven days. After 90-day curing, the substitute cement with a 65% replacement ratio can almost match the strength of OPEC (about 300 kg/cm^2), but with a replacement ratio increased to 80%, the strength can reach only 200 kg/cm^2. This indicates that less $Ca(OH)_2$ than necessary had been released from an insufficient volume of cement to slag powder to sustain the growth of concrete strength.

For the substitute cement made by adding fly ash only, the concrete strength is lower than that made with slag powder for the samples after curing for 90 days. For a replacement ratio of 30% the strength grew rapidly between a curing period of 28 and 90 days and results were similar to those with a replacement ratio of 15% after 90-day curing.

In the first seven days after concrete deposition, the concrete strengths were very similar for concretes consisting of natural aggregate or of slags, but the strength of concrete with slag aggregates increases more rapidly after 28 days of curing. It is known that the consolidation process of cement is almost complete within seven days after deposition. Therefore, the larger strength of concrete with slag aggregate after 28 days of curing is believed due to the coarse and porous surface texture of the slag, which makes the cementation more efficient between cement mortar and slags.

As for the effect of cleaning of the slags (by washing away the covering powders with water) on concrete strength, the results from tests with a water/cement ratio of 0.59 and a slag powder replacement ratio of 0.65 show that the strength of concrete with uncleaned (raw) slags is smaller than that of concrete with cleaned slag. The difference increased as the curing time increased and the maximum difference was about 13%. This was found to be caused by the presence of the covering powder on the raw slags which could deter the cementation reaction between cement mortar and slags.

Testing the effect of the curing environment on the concrete strength showed that sea water rather weakens the concrete strength but, on the contrary, can still keep the same strength after different curing periods in the water. The results also suggest that concrete deposition after curing in air in the field will reach the lowest strength compared with that from fresh or sea water curing and the slag powder or fly ash concrete strength can exceed that of selected Portland concrete after 28 curing days.

The results from different locations show that the minimum concrete strengths were all larger than 140 kg/cm^2 and the values for waste-made concrete at water/cement ratio of 0.59 after 90-day curing were all larger than OPEC concrete. Moreover, the maximum values for each test specimen were all larger than 175 kg/cm^2 and were 300 kg/cm^2 from 65Ss65 and 262 kg/cm^2 from 59Ss65 concrete.

The results showed that OPEC and 65Ss65 concrete specimens exhibited largest strengths on the surface after 28-day and 90-day curing periods. Although the slag powder and fly ash mixed concretes showed higher strength in the initial stage of curing, several micro cracks were found on the surface due to the effects of temperature and humidity changes. As a result, their surface strength values obtained by this testing method were less than that of OPEC concrete. The values from this test were all less than that of core tests, which implied that results from rebound number hardness testing usually underestimate the strength of the pozzolanic material concrete.

The results given are for average values between two measuring points in the concrete armour units and all showed lower strength values than the cylindrical specimens in core testing at different curing periods.

Table III shows that the water quality before and after the start of the project using land filling of industrial waste exhibited only a slight increase in chromium concentration although lower than the safety limit. This demonstrated that the land filling did not contaminate the nearby water environment. In particular, the phenomenon of yellowish sea water caused by the wind-eroded waste has been lessened due to the application of a geotextile to the bottom of the enclosing breakwaters.

CONCLUSIONS

From an engineering point view, materials made with suitable combination ratio of slag powder and fly ash can replace conventional cement and still satisfy the design criteria.

The application of the slags as an alternative coarse aggregate can reduce the effects of creeping and shrinkage compared with the natural aggregates.

Temperature and humidity can have more influence on concrete made with a larger replacement ratio of slag powder or fly ash as well as that made with larger water/cement values. In particular, the larger the exposed surface area of the concrete armour unit per unit volume, the smaller the concrete strength, which highlights the importance of the curing process, especially in the initial stages.

The use of slag powder or fly ash can reduce the temperature and the associated stress caused by the cementation process in concrete armour units in the field. It is found that in the first three days of curing, the temperature in the OPEC concrete increased more rapidly than in slag powder or fly ash replaced concrete. This is believed to be caused by the gradual process of pozzolanic reaction, and can delay the rate of temperature accumulation.

The concrete strength at each location is closely related to the local temperature development. Faster temperature accumulation at certain locations can induce earlier cementation but the effects diminished after the 90-day curing period. However, slower temperature accumulation in the initial stage of curing can strengthen the cementation and results in stronger strength development at the later stage of curing.

From field experience after the application of the two types of concrete mixture (shown in Table IV: 59Ss65f15 and 59Ss65) the reuse of the waste material in the concrete was found to save insignificant money so far, but the long term economic value could be significant due to decreasing natural resources. In addition, field observations also suggest that waste-made concrete units can be applied in regions subject to indirect wave action and natural concrete-made armour units in regions

Table IV Concrete mixture content of cast-in-place square concrete block (0.59 Ss65f15 combination)

Mixture Content	Wt. (kg/m^3)	Note
Water	168.8	
Cement	57	Type I cement
Slag powder	185	Fineness above 370 m^2/kg
Fly ash	42.7	Meets ASTM C311-86 and C618-8 requirement
Sand	681	Water content 7%
Coarse slag aggregate	1,033	Ratio >35 mm/<35 mm = 4:6

subject to direct wave action.

The reuse of non-toxic industrial waste, which is abundant in a prosperous developing municipal city such as Kaohsiung, not only lessens the burden incurred from waste disposal but can also create more land for the city, e.g. about 460 additional acres are expected in the first part of this project. This study introduces the preliminary engineering practice and provides a good example for future application of similar non-toxic waste to reclaim the eroded coastal zones on the Taiwan Island. Finally, it is recommended that more studies should be carried out to set up a more complete model including continuous environmental monitoring to prevent nearby regions from being polluted.

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