Coventry University and
The University of Wisconsin Milwaukee Centre for By-products Utilization,
Second International Conference on Sustainable Construction Materials and Technologies
June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
Main Proceedings ed. J Zachar, P Claisse, T R Naik, E Ganjian. ISBN 978-1-4507-1490-7
http://www.claisse.info/Proceedings.htm

Use of Iranian Industrial Waste for Cement Replacement in Low Strength Concrete and CLSM

Mohammad Alizadeh Kharaazi[a] and Eshmaiel Ganjian[b]

[a] *Sharif University of Technology, Civil Engineering Department, Azadi Ave. Tehran, Iran. E.mail:<alizadeh@sharif.edu>*
[b] *Coventry University, Faculty of Engineering and Computing, Department of The Built Environment, Coventry CV1 5FB, UK. E mail: <E.Ganjian@Coventry.ac.uk.>*

ABSTRACT

This study concentrates on the industrial waste materials which have pozzolanic and / or cementitious property and can possibly be used in concrete mixtures or in controlled low strength material (CLSM) mixes. These materials as a cementitious or pozzolan not only reserve the environment but can replace Portland cement or reduce it. As in production of one tonne of Portland cement about one tonne of carbon dioxide is released into the environment, the aim is to reduce the amount of the Portland cement use in construction materials as much as technically possible.

The research shows that some of the industrial waste materials or by-product materials which are produced in a vast amount per year can be reused as a pozzolan and cement additives in construction material mixtures.

INTRODUCTION

Today, concrete is a popular material in construction. Not only, the economy and technical aspect of concrete is important, but environmental and energy consumption is too. Reduction of Portland cement without reducing performance of concrete is very important for huge projects that need a lot of cement. Today, pozzolan and cementitious materials plays an important role in concrete. Wastes of industries and constructions which have pozzolanic or cementitious property, not only can reduce environmental pollution and energy consumption of construction industry, but make it cheaper.

Waste materials cause pollution in the world and the industrial waste streams are increasing annually in the world. Iranian industries produce a huge amount of industrial waste material which pollute environment, commonly no recycling or any reuse or treatment is being performed on them. Hence waste materials are a critical problem for the Iranian environment and consume enormous resources and capitals of Iran to landfill.

Industrial waste materials have been subject to numerous researches in construction materials. Some showing pozzolanic properties [Dovidovits 1994, Roy 1999, Ay and Ünal, 2000, Ganjian et al Sep 2004, Oct 2004, Mour et al 2007, Rodríguez et al 2008, Naceri and Hamina 2009 and Federico and Chidiac 2009] and very limited materials show self cementitious properties [Sing and Garg 1999, Sabir et al 2001, Ganjian et al 2009].

[Roy 1999] produced a compressive summary of some important industrial waste materials and references outlining steps in the development of alkali-activated and Pozzolanic cements. While [Pera and Amrouz 1998, Rodríguez et al 2008, Banfill et al 2009 and Rosario et al 2009] showed the pozzolanic property of Metakaolin from Paper Sludge, others [Ay and Ünal, 2000, Mour et al 2007, Naceri and Hamina 2009 and Federico and Chidiac 2009] showed the pozzolanic properties of waste ceramics, copper slag waste, waste brick, and waste glass respectively.

Industrial waste can also be used for the production of CSLM [Katz and Kovler 2004 and Ganjian et al 2006]. CLSM is used mainly for filling cavities in civil engineering works, in which the application of granular fill is either impossible or difficult [ACI 229, 1999]. The production technology, however, is similar to the production of concrete. The mechanical strength of CLSM is generally low (unconfined compressive strength of 0.5–2 MPa) permitting re-excavation in the future, and the material is flowable, allowing perfect filling of any void. Cement content is generally in the range of 50–100 kg/m3 of CLSM to provide the desired strength. High workability is achieved through the use of high amounts of mixing water or by using admixtures (air entraining agents, plasticizers, etc.)

This experimental work investigates the possibility of utilisation of some Iranian industries wastes and by products as pozzolanic or cements replacement materials for CLSM or concrete.

EXPERIMENTAL PROGRAMME

First stage; preliminary tests

Well over one hundred waste materials were supplied for a preliminary test. A set of specimens was made with water, another set was made with low concentration of limewater solution and a third set was made with saturated lime solution. The setting of these specimens were checked and recorded first and then they were kept submerged under water to check if they were disintegrated. The materials not disintegrated were selected for the next stage of testing.

Second stage test

Mortar mixtures of about eighty materials selected in stage one, were mixed with the mixture designs given in Table 1 in accordance to ASTM C311.

Table 1. The Mixture Code and Designs in Accordance to ASTM C 311

Control Mix	Mortar containing 250 gr. Cement, 687.5 gr. standard sand and 121 ml of water.
Waste Mix (W Mix)	Mortar containing 200 gr. Cement, 687.5 gr. standard sand, 50 gr. waste and water required for flow ±5 mm of control mixture.
Normal Mix (N Mix)	Mortar containing 200 gr. Cement, 687.5 gr. standard sand, and 121 ml of water.
S F Mix	Mortar containing 200 gr. Cement, 687.5 gr. standard sand, 50 gr. Silica Fume and 140 ml of water.
Additional Mix (Add Mix)	Mortar containing 250 gr. Cement, 687.5 gr. standard sand, 50 gr. waste and water required for flow ±5 mm of control mixture

The mixing was carried out according to ASTM C109. The waste materials were crushed and passed through sieve No. 200 before mixing. The mixtures were then poured into 50 mm steel cube moulds and left wrapped for 24 hours before being demoulded. Hand compaction was used to get full compaction for each mix. The moulds were compacted in two layers using 32 blows for each layer.

The cubes were kept in water of 20 ± 2°C until 7 days and 28 days for compression tests.

The cubes dimensions were measured to 0.1mm and the uniaxial compression tests were carried out according to BS EN 12390-3:2002. Three specimens were tested for each age and the average strength was used for analysis.

RESULTS

The strength activity index with Portland cement (Ic) was determined as shown in Table 2 in the same way as ASTM C311 define it. Silica-fume index (Is) was similarly designed by authors for comparing waste to Silica-fume mixture. The (Ia) and (In) were also designed in a similar manner as shown in Table 2.

Table 2. The Indexes of Waste Mixtures

Ic	Ratio of Strength of Waste mixture of wastes specimen (maximum strength) to strength of Control mixture
In	Ratio of Strength of Waste mixture of wastes specimen (maximum strength) to strength of normal mixture
Is	Ratio of Strength of Waste mixture of wastes specimen (maximum strength) to strength of Silica Fume mixture
Ia	Ratio of Strength of Waste mixture of wastes specimen (maximum strength) to strength of add Mix mixture

The indexes as defined in Table 2 were computed and are shown in Table 3 and Table 4.

Table 3. The Indexes of Stage 2 Materials

Material	**Ic (%)**		**Is (%)**		**Ia (%)**	
	7 days	28 days	7 days	28 days	7 days	28 days
Cement blocks	23.2	30.4	59.5	70.3	152.9	140.8
Coral reef	23.2	45.4	47.9	64.4	152.9	210.2
Alkali firebricks	67.0	63.9	67.1	51.4	441.2	295.9
Cement factory waste [1]	40.2	64.8	67.1	71.9	264.7	300.0
Waste of cement factory [2]	75.9	70.9	60	59.6	500.0	328.6
Hollow brick	77.7	89.4	60.7	75.8	511.8	414.3
Mid-way waste [3]	64.3	95.6	47.9	75.8	423.5	442.9
Ferro-silica	49.1	87.7	98.8	153.3	323.5	406.1
Sanitary porcelain	97.9	141.2	66.4	73.2	138.2	78.5
Travertine rock	114.6	144.5	78.6	50.7	161.8	80.4
Granite rock	70.5	70.7	-	41.7	71.7	73.4
Clay clinker & Stove firebrick	73.8	68.4	72.1	81.2	75.0	71.1
Tile waste	59.2	57.9	79.8	76.2	133.3	157.3
lime waste	49.1	27.7	-	51.9	110.7	75.4
Iron ore waste	179.7	80.7	-	-	122.3	105.0
Pottery	189.1	93.4	79.6	95.1	128.7	121.6
Low heated bricks	126.6	69.1	-	70.6	86.2	89.9

[1]– Tehran cement factory waste
[2]- Tehran cement factory raw material waste (pozzolanic soil)
[3]- Tehran cement factory mid-way waste

Table 4. The Indexes of Stage 2 Materials

Materials	Ic (%)	In (%)
	28days	28days
Green rock of Khorasan [4]	60.9	101.6
Ammonium Silicate	87.8	146.4
Esfahan Cement Factory waste	60.2	100.3
Potassium silicate	46.3	175.0
Calcite	64.0	242.2
Neka paper & pulp factory sludge waste	96.7	366.0
Sodium carbonate	45.1	170.5
Used Azure pigment waste	214.7	244.2
Bromide	184.9	210.3
Pest Poison factory waste	237.4	270.0
Meta Kaolin	136.2	154.9
Colour factory waste	233.2	265.2
Calcium silicate	111.7	112.4
Lead slag	117.8	118.4
Nickel-brass slag	105.4	106.1
Copper slag	108.6	109.2
Decorative bricks	100.3	100.9
Copper-Nickel slag	118.9	119.6
Gypsum kiln slag	52.3	154.9
Di-sodium phosphate	38.6	114.5
Calcium carbonate	144.7	163.6
Barium carbonate	92.0	104.0
Titanium oxide	89.4	101.1
Heated fire bricks	80.9	89.2
Steel plant kiln dust	121.2	133.6
Cast iron slag oxide	95.4	105.2
Aluminium & Sodium ore	45.5	71.9

wastes		
Tile paste waste	70.4	100.0
Calcium carbonate plaster	82.1	116.7
Cottonseed factory waste	24.1	34.3
Decorative Travertine rock powder (green colour) [5]	121.2	172.2
Kavosh Weld factory slag waste	109.8	156.0
Iran Weld electrode factory slag waste	106.2	150.9
Zinc sulphate of Zarin Dung factory	93.2	132.4
Sediment Marble dust	78.3	80.6
[4]- Province in the north of Iran [5]- Fars province rock mines		

ANALYSIS AND DISCUSSION

The strength activity index with Portland cement (Ic) of materials shows the pozzolanic property of the waste. The silica fume index (Is) of materials shows the pozzolanic property of the waste comparing to silica fume. The normal index (In) and add index (Ia) of materials with less than 100, indicate that the material has negative impact on cement hydration and reduces the compression strength, so they are not suitable for adding to mixtures.

Third stage; waste material composition test

From second stage; Decorative Travertine Rock Powder (green colour) from Fars province (TRP) with estimated production of 40 tons/day for this province alone, Paper Factory sludge of Neka in Mazandaran province (PFK) with estimated 4 tons/day for this unit, Ferro-Silica Powder produce from crushers of Middle-East Glass Industries of Semnan (FSP) with estimated 5 tons/day for this unit, heated brick kiln wastes (LHB) with estimated 4 tons/day for this unit, Heated Kaolin of tile factory of Yazd province (MK) with estimate 400 tons/day for Iran, Cast iron mills slag in south of Tehran (SIS) with estimated 40 tons/day for Tehran and Weld Factory slag wastes in south of Tehran (WFS) with estimate 0.35 tons/day for this unit, were selected for further testing.

Each selected material was made with four different compositions (i.e. 25, 50, 75 and 100 percent) and tested for compressive strength at 28 days.

New indexes as defined in Table 5 were computed.

Table 5. The Indexes of Materials for the Third Stage

Ioc	Ratio of 28days Strength of optimum composition mixture of particular waste specimen (maximum strength) to 28days strength of Control mixture.
Ios	Ratio of 28days Strength of optimum composition mixture of particular waste specimen (maximum strength) to 28days strength of Silica Fume mixture.
Ion	Ratio of 28days Strength of optimum composition mixture of particular waste specimen (maximum strength) to 28days strength of N mixture

Results of the strength test at 28 days and the calculated indexes are shown in figure 1 and more details of the mix designs for these mixes are given in Table 6. The optimum compositions shown in this table are for the 50 grams of waste used with 200 grams of cement. The chemical compositions of the selected waste materials studied are given in Table 7.

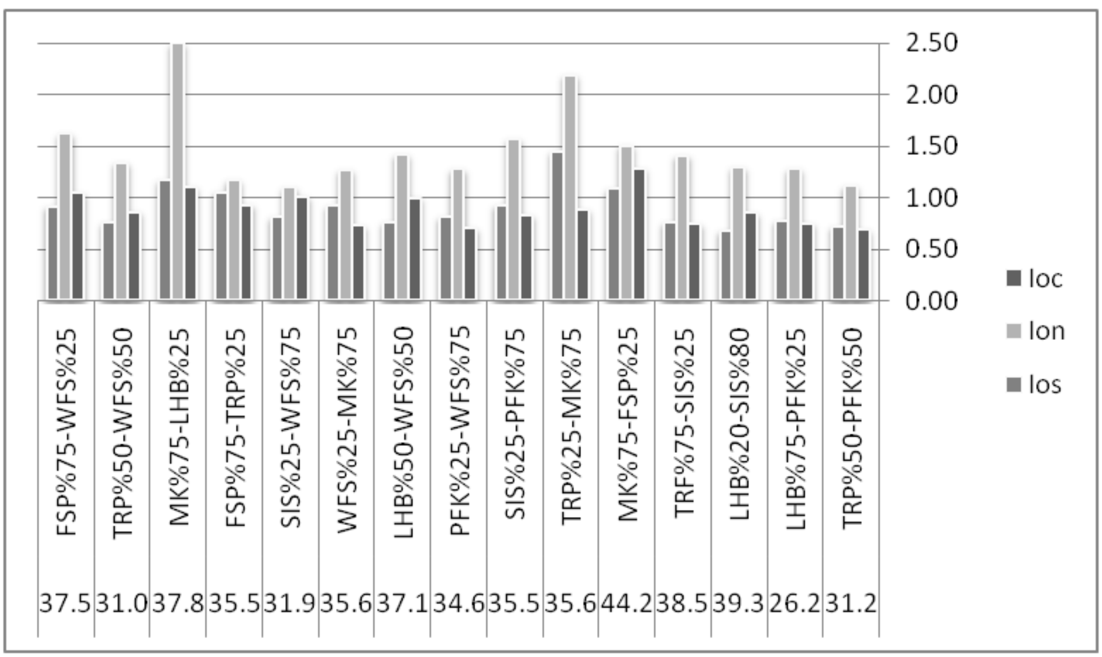

Fig. 1. Bar Charts of Indexes for Waste Material Selected with Their Optimum Composition and Compressive Strength at 28 Days in MPa.

Table 6. The Strength and Water Content of Mixes with Optimum Compositions of the Waste Proportion Used with Portland Cement.

Mix code & composition in percentage	28 days Strength (MPa)	water (ml)
TRP50 - PFK50	31.2	110
LHB75 - PFK25	26.2	115
LHB20 - SIS80	39.3	133
TRP75 - SIS25	38.5	120
MK75 - FSP25	44.2	120
TRP25 - MK75	35.6	140
SIS25 - PFK75	35.5	120
PFK25 - WFS75	34.6	125
LHB50 - WFS50	37.1	105
WFS25 - MK75	35.6	120
SIS25 - WFS75	31.9	120
FSP75 - TRP25	35.5	120
MK75 - LHB25	37.8	116
TRP50 - WFS50	31.0	120
FSP75 - WFS25	37.5	120

Table 7. Chemical Compositions of Selected Wastes in the Third Stage.

	TRP	PFK	FSP	LHB	MK	SIS	WFS
CaO	49.2	11	-	7.72	2.5	9	4
SiO_2	4.7	34	46	46.48	69.6	31	32
Al_2O_3	1	24	4	27	13.8	3	-
$Fe_2 O_3$	2	3	50	6	2	26	47
MgO	0.4	9	-	1.84	1.2	-	-
K_2O	-	8	-	-	3	-	-
Na_2O	-	5	-	-	2.8	-	-
So_4	1.1	-	-	1.74	.05	.5	-
Cl	.01		-	0.007		-	-

The strength activity index with Portland cement (Ioc) of the materials shows the pozzolanic property of the optimum composition waste and similarly the silica fume optimum composition index (Ios) of the materials shows the pozzolanic property of the waste comparing to silica fume.

The optimum normal composition index (Ion) of the materials with less than 1 indicates that the material has negative impact on cement hydration and reduces the compression strength, so they are not suitable for adding to mixtures.

Figure 1 and Table 6 show that fifteen mixes listed have strong pozzolanic indexes and show comparable mechanical strength to Portland cement and silica fume concrete up to 28 days of age. Travertine Rock Powder (TRP), Paper Factory Sludge (PFK), Ferro-Silica Powder (FSP), Heated brick kiln wastes (LHB), Heated Kaolin of tile factory (MK), Cast iron mills slag (SIS) and Weld Factory Slag (WFS) have excellent pozzolanity indexes and are cementitious. This is due to the high CaO and SiO2 content of these materials (see table 7). These materials can be used for cement replacements and be used for non reinforced concrete for different civil engineering applications. However their long term durability must be studied in future studies.

CONCLUSIONS

The following general conclusions can be drawn from the results of the 28 days strength of mortar specimens made with selected industrial waste materials:

- Travertine Rock Powder (TRP), Paper Factory Sludge (PFK), Ferro-Silica Powder (FSP), Heated brick kiln wastes (LHB), Heated Kaolin of tile factory (MK), Cast iron mills slag (SIS) and Weld Factory Slag (WFS) show excellent pozolanic properties and can be used as cement replacement materials in concrete.
- Material listed above have Ioc indexes of about more than 1 and can be a good partial replacement for cement.
- The 75 percent by weight Meta-Kaolin (MK) and 25 percent by weight Ferro-Silica Powder (FSP) has the best composition result in the ranges studied and gives the best replacement for cement with Ioc about 1.25.
- The 75 percent by weight Meta-Kaolin (MK) and 25 percent by weight decorative Travertine Rock Powder (TRP) has the best composition result and the best replacement material comparing to silica fume with Ios of about 1.4.

REFERENCES

ACI, 229R, 1999. Controlled low strength materials. , American Concrete Institute, Farmington Hills, MI, USA.

Ay, N., and Ünal, M. (2000). "The use of waste ceramic tile in cement production." *Cement and Concrete Research , 30(3),* 497-499.

Banfill, P. F. G., Rodríguez, O. b., Sánchez de Rojas, M. I., and Frías, M. (2009) "Effect of activation conditions of a kaolinite based waste on rheology of blended cement pastes." *Cement and Concrete Research, 39(10),* 843-848.

Dovidovits, J. (1994). “High-alkali Cements for 21st Century Concretes.” *ACI Special publications, Vol 144, American Technical Publishers ltd.,* pages 383ISBN0065-7891.

Federico, L. M., and Chidiac, S. E. (2009). “Waste glass as a supplementary cementitious material in concrete – Critical review of treatment methods” *Cement and Concrete Composites, 31 (8),* September 2009, Pages 606-610.

Ganjian, E., Claisse, P.,Tyrer, M. and Atkinson, A, (2004). “Selection of cementitious mixes as a barrier for landfill leachate containment”, *ASCE Journal of Materials in Civil Engineering, 16(5)*, 477-486, Oct. 2004.

Ganjian, E., Claisse, P.,Tyrer, M. and Atkinson, A, (2004). “Preliminary investigations into the use of secondary waste minerals as a novel cementitious landfill liner”, *Construction & Building Materials Journal, 18(9),* 689-699, Sep. 2004.

Ganjian, E., Claisse, P and Tyrer, M, (2006).“Use of unclassified ashes as controlled low strength materials for a novel cementitious landfill liner”, *International Coal Ash Technology Conference, Birmingham, UK, B09, ISBN10: 0-9553490-0-1, ISBN 13: 978-0-9553490-0-3,* 14th – 17th May 2006.

Ganjian, E, Sadeghi Pouya, H and Claisse, P, (2009). Chapter: “Plasterboard and Gypsum Waste as a Novel Cementitious Binder”, pp. 1-115, in “Concrete Materials: Properties, Performance and Applications”, Nova publishers, 593 pages, 3rd Quarter 2009, ISBN: 978-1-60741-250-2.

Katz, A., and Kovler, K., (2004). “Utilization of industrial by-products for the production of controlled low strength materials (CLSM).” *Waste Management, 24(5),* 501-512.

Moura, A., Gonçalves, J., and Lima, M. (2007). “Copper slag waste as a supplementary cementing material to concrete” *Journal of Materials Science, 42 (7).*

Naceri, A., and Hamina, M. (2009). “Use of waste brick as a partial replacement of cement in mortar” *Waste Management, 29(8),* 2378-2384.

Pera, J., and Amrouz, A. (1998). “Development of Highly Reactive Metakaolin from Paper Sludge” *Advanced Cement Based Materials*, 7(2), 49-56.

Rodríguez, O., Frías, M., and Sánchez de Rojas, M. (20089). “Influence of the Calcined Paper Sludge on the Development of Hydration Heat in Blended Cement.” *Journal of Thermal Analysis and Calorimetry, 92(3).*

Roy, D. M. (1999). “Alkali-activated cements Opportunities and challenges.” *Cement and Concrete Research, 29(2),* 249-254.

Rosario, G., Virginia, R., Iñigo, V., and Moisés, F. (2009). “Influence of thermally activated paper sludge on the behaviour of blended cements subjected to saline and non-saline environments.” *Environmental Science and Pollution Research, 16(3).*

Sabir, B., Wild, S., and Bai, J. (2001). “Metakaolin and calcined clays as pozzolans for concrete: a review”, Cement and Concrete Composites, *23(6),* 441-454.

Singh,M., and Garg, M. (1999). “Cementitious binder from fly ash and other industrial wastes.” *Cement and Concrete Research, 29(3),* 309-314.