Comparison between MSW Ash and RDF Ash from Incineration Process

Ni-Bin Chang* , H. P. Wang* , W. L. Huang , K. S. Lin*** and Y. H. Chang*****

presented to

Fifth North American Waste-to-Energy Conference

Research Triangle Park, NC

April 21-25, 1997

* Associate Professor, Department of Environmental Engineering, National Cheng-Kung Unicversity, Tainan, Taiwan, R.O.C.
** Associate Professor and Chairman, Department of Civil Engineering, National Kaohsiung Institute of Science and Technology, Kaohsiung, Taiwan, R.O.C.
*** Graduate Student, Department of Environmental Engineering, National Cheng-Kung Unicversity, Tainan, Taiwan, R.O.C.

Comparison between MSW Ash and RDF Ash from Incineration Process

Ni-Bin Chang, H. P. Wang, W. L. Huang, K. S. Lin and Y. H. Chang

Department of Environmental Engineering
National Cheng-Kung University
Tainan, Taiwan, Republic of China

ABSTRACT

Resource recovery plants with waste sorting process prior to incineration have not been successfully developed in many developing countries. The reuse potential of incineration ash in light of toxicity and compressive strength remains unclear due to the inhomogeneous composition and higher moisture content of solid waste in Taiwan. A comparative evaluation of the ash generated from two types of incineration processes were performed in this paper. The results indicate that fly ash collected from both types of incineration processes are classified as hazardous materials because of higher metal contents. The reuse of bottom ash collected from refuse-derived fuel incineration process as fine aggregate in concrete mixing would present 23% lower compressive strength as compared with the normal condition.

INTRODUCTION

In the midst of fast paced economic activities in Taiwan, the society demands and consumes a lot of natural resources and raw materials in the creation of products to enrich people's life. To cope with large amount of solid waste disposal with the landfill space at a preminm in this tiny island, over thirty municipal incinerators were planned to be built in the major metropolitan areas within the next decade. It is estimated that there will have over two millions tonnes of incineration ash generated every year after the year 2000 which would still accelerate the depletion of limited landfill space. However, continuous population growth requires more housing projects which inevitably request more production of river sand as part of the materials in concrete mixing. This further poses problems of erosion in light of the natural balance in the river eco-system. In recent years, several communities in Taiwan encounter an issue that the house they live were built using sea sand as surrogate raw materials in concrete mixing. The fast deterioration of those building would also create a hazard to the residents living in those communities. The term "sustainable development" has special meanings as the wellbeing of a population of twenty million in Taiwan, with the area no larger than thirty-six thousand square kilometers, must be sustained probably by the reuse of incineration ash as part of the raw materials in the future construction programs. This study tries to achieve part of the life cycle analysis of comsumer products as they are destined for final disposal in the municipal incinerators. The evaluation of reuse potential of those end products from incinerators can then be regarded as an action of resource conservation and recycling in the entire life cycle analysis.

Although Taiwan has set a bold agenda of solid waste incineration programs to conserve the landfill space in the last few years, the continuing thinking of an integrated incineration system with the sorting process as a pretreatment unit to improve the incineration efficiency and generate better quality of flue gas and ash has never been tempered. At least two proposals for installing such a sorting process prior to the large scale municipal incinerators, located in the City of Tai-Chung and the County of Taipei, were raised in 1996. In addition, such an integrated incineration system was also chosen for planning several medium size modular incinerators, that are located in the rural areas in Taiwan. But the property and reuse potential of those RDF ash remain unclear. The incineration ash from the MSW burning is currently being used for landfilling only in Taiwan. Backfilling of construction sites, subbase in road construction, and to some extent, reuse for concrete mixing have been fully carried out in several laboratory experiments. This analysis emphasizes the comparative study of property characterization and reuse potential of ash from MSW and RDF incineration processes, using local waste flow as fuels in Tainan area of Taiwan.

Two major facilities, located in Tainan area of Taiwan, were used as pilot plants in this experiment. One is a refuse-derived fuel process, and the other is a modular incinerator. Hence, two types of incineration processes can be arranged. One has a dedicated sorting process associated with a modular incinerator while the other has not such a sorting plant prior to incineration. The samples of municipal solid waste (MSW) in Tainan area of Taiwan were collected and then the refuse-derived fuel (RDF) were generated for the subsequent incineration. Incineration ash from the waste burning process were produced and collected from the bottom of ash discharge and the electrostatic precipitator hopper, as denoted by the "bottom ash" and "fly ash" respectively in this study. The properties of incineration ash were specifically characterized and the reuse potential of bottom ash as part of the raw materials in concrete mixing was also examined. In the first stage analysis, the unwashed incineration ash were tested and analyzed for TCLP (Toxicity Characteristic Leaching Procedure) metals and chemical composition using XRD and SEM/EDS techniques. In the second stage analysis, to further evaluate the reuse potential of bottom ash, the washed bottom ash from both types of incineration processes were tested by seieve analysis and compressive strenth analysis. Final suggestions were made based on the tested properties of those incineration ash.

LITERATURE REVIEW

In the last decade, a number of credible research efforts were carried out in both the European countries and United States ([1]~[3]) and the efficiency and effectiveness of resource recovery from solid waste associated with incineration system has been fully discussed ([4]~[12]). However,the impacts of solid waste sorting on incineration remain uncertain due to the higher moisture content and plastics in solid waste composition in Taiwan, which is not fairly representative of most other countries.

In addition, ash properties have been fully characterized in several municipal incinerators, such as in New York City, California, Singapore, and so on ([13]-[17]). Engineering evaluation of resource recovery for incineration ash has been performed ([18]-[19]). Specific purposes of ash utilization were fully discussed, such as the recovery and reuse of ash as the raw materials in concrete mixing ([20]-[23]), the reuse of ash as the subbase materials in road construction and gentechnical applications ([24]-25]), and even the recovery of fly ash as zeolite [26].

FACILITY DESCRIPTION

Solid Waste Sorting System

As is illustrated in Figure 1, the solid waste sorting process consists of three major units: shredding, air classification, and screening. The facility can process 30 tons/hr at maximum capacity per one line. The MSW is delivered to the facility by packer trucks. A bag-ripping unit, to open plastic bags, initializes the sorting process. Ferrous metal is then extracted from the MSW stream using magnets. Recovered ferrous metal is conveyed to a ferrous storage bin from where it is recycled. MSW is then processed in a vertical hammermill shredder to reduce it to a normal size. Shredded MSW is taken to an air classifier, using a belt-type conveyor. Non-ferrous materials, such as aluminum cans and combustibles are crushed by the vertical hammermill shredder. A manual sorting unit or eddy current separator could be added prior to the vertical hammermill shredder for the recovery of aluminum cans in the future. The air classifier, blowing with a regular air stream of 200 m^3/min from the vertical hammermill shredder, is intended to separate the inert materials, such as glass, ceramics, and so on, to reduce the content of heavy non-combustible material in he residual MSW streams. Light materials, passing through the air classifier, are sent into the trommel screen for advanced separation. The dimensions of the openings on the surface of trommel screen can be varied to fine-tune the processing function and assure maximum combustibles recovery. The trommel is designed with two concentric shells. The outer shell, with 2.33 meters in diameter and 4.3 meters in length, has many circular holes on the surface which is designed to remove the shredded materials smaller than 25 mm. The inner shell, with 1.9 meters in diameter and 4.56 meters in length, separates partial waste stream with the size between 25 and 100 mm. Three waste streams can be trommeled. In other words, particle size is controlled by the openings design on the surface of the trommel such that the material with the particle size less than 25 mm (trommel underflow) and the particle size between 25 mm and 100 mm (trommel middle flow) are separately arranged by two different sets of openings with a concentric shell configuration. The overflow, passing through this trommel screen, presents the most light portion in the MSW with the size greater than 100 mm (trommel overflow) , and can be identified as fluff-RDF. However, both outputs with particle size larger than 100 mm and between 25 mm and 100 mm can be used as fuels in the incineration facilities.

SolidWaste Incineration System

Figure 2 presents the system configuration of the modular incinerator. The 100 Kg/hour modular incinerator was designed is equiped with an electrostatic precipitator and a wet scrubber. From the silo the RDF or MSW is fed into the furnace where the combustion takes place on a 3-step movable grate system. The flue gases generated pass through the first furnace and is cooled down at the outlet of secondary furnace. The heat exchanger is installed at the outlet of secondary furnace for the preheating of auxiliary air. The flue gases are eventually led through air pollution control system, consisting of a conventional electrostatic precipitator (EP) followed by a wet scrubber. Reheat is provided to prevent visible flue gas emissions due to higher moisture content.

TCLP ANALYSIS

Samples of fly ash and bottom ash were analyzed in accordance with the TCLP requirements. Tables 1 and 2 list the analytical results of TCLP tests for both bottom ash and fly ash. Two replicates were prepared to meet the QA/QC requirements that generate the data ranges in both Tables 1 and 2. The leachability of regulated heavy metals is affected by waste composition, its combustion history, and handling method. This would differentiate the fundamental difference of ash from burning MSW and RDF.

The extracted metals from the fly ash in the RDF incineration process generally exhibit relatively lower concentrations. However, testing fly ash revealed that both types of fly ash generated from burning MSW and RDF can be classified as hazardous materials due to higher heavy metal content. But the extracted metals from the bottom ash of MSW and RDF burning exhibit relatively lower concentrations. The reason for the higher Zinc concentration leached from RDF bottom ash is still unclear. This is probably due to the higher percentages of paper content with printing ink in the RDF that is not Zinc-free products. Table 2 shows that extractable cadmium concentrations in both types of fly ash are far beyond the regulatory levels. This substantial differences would make the fly ash subject to post-treatment requirements, such as stabilization, solidification, vitrification, and even melting processes.

CHEMICAL COMPOSITION ANALYSIS

In order to have more comprehensive insight, tasks of phase identification of both fly ash and bottom ash by X-ray diffraction and SEM/EDS techniques have been performed in this analysis. Table 3 lists the chemical compositions of those fly ash and bottom ash. On the average, the ash mainly comprise of SiO_2, CaO, Al_2O_3, Fe_2O_3, ZnO, MgO, and Cr_2O_3. It appears that Fe_2O_3 constitutes the major part of fly ash. Besides, CaO is the highest content and SiO_2 is the second largest group in those bottom ash.

EVALUATION OF REUSE POTENTIAL AS FINE AGGREGATE

Sieve Analysis of Bottom Ash

Wider particle distribution exists in the bottom ash of MSW. The shape of the particles of MSW ash is relatively irregular and flaky. Higher amount of aluminum cans, metal tubes, iron wires and other ferrous metals exist in the MSW bottom ash that makes the recovery, recycle and reuse processes become much more difficult. After removing those impurities, Figure 3 illustrates the grading of the MSW and RDF bottom ash. Due to the poor setting of concrete were reported when "raw" incineration residues are used, washing process was therefore employed to remove part of light and fine materials before the samples were used in concrete mixing [21]. The results of sieve analysis of "unwashed" and "washed" ash samples were both listed in Tables 4 and 5. It shows that the particle size distributions of MSW and RDF bottom ash present similar patterns. But relatively higher percentage of light and fine materials exists in MSW bottom ash.

Compressive Strength Analysis

Table 6 lists the properties of normal sand, washed MSW and RDF ash. The fineness modulus of the MSW and RDF particles are 3.34 and 3.59 respectively, indicating a rather coarse grading. The specific gravity of the washed MSW and RDF samples are 2.27 and 2.38, respectively. The water adsorption values are 2.0%, 9.0%, and 7.4% corresponding to the normal sand, MSW, and RDF ash respectively. Although the specific gravity of washed incineration ash is similar to natural sand, the water adsorption value is three more times higher. In addition, the residual carbon contents in MSW and RDF bottom ash ranges from 2.63-2.66 (%) and 0.63-0.66 (%), respectively. These values indicate that MSW bottom ash has a higher amount of unburnt materials.

Tests of compressive strength were conducted using washed bottom ash as fine aggregate in a normal mix of 1:2:4 (cement:sand:coarse aggregate) at water cement ratio of 0.7. Ordinary Portland cement was used as it would be in the normal concrete preparation. The coarse aggregate is 20-mm maximum size crushed granite. The bulk density of concrete mixes using normal sand, MSW, and RDF ash as fine aggregate are 2,340 Kg/m^3, 2,100 Kg/m^3, and 2,110 Kg/m^3, respectively. The slump values of concrete mix with normal sand, MSW and RDF ash are 100 mm, 10 mm, and 20 mm, respectively. The initial setting time for the concrete with MSW or RDF ash is about 3 hr as compared to 2 hr for the concrete with normal sand. In general, concrete with incineration ash as fine aggregate have longer setting times than the samples with normal sand. It appears that all the mixes with incineration ash have lower workability. However, the setting times are well within the requirements of ASTM standards.

Cubic specimens (12mmx24mm) were then prepared and compressive strength of the specimens at various ages (i.e., 3, 7, 14, and 28 days) were tested according to ASTM Standards. Table 7 shows the ranges and averages of compressive strength of concrete mixes. The strength of different batch with normal sand mixes are generally higher than that of the mixes with washed MSW or RDF bottom ash. The compressive strength ratio versus age for those samples are depicted in Figure 4. The curve corresponding to the case using MSW bottom ash as fine aggregate present inconsistent trend as compared with the other two curves. This is probably due to the inhomogeneous nature of MSW ash samples. The average compressive strength of ash mixes are lower than that of the normal sand mixes at all ages. For concrete mixes with water-cement ratio of 0.7, the compressive strength of the MSW and RDF ash mixes are about 54.7% and 35.2% lower than normal sand mixes at the final stage with the age of 28 days, respectively. The reason why concrete mixes with RDF bottom ash presents higher compressive strength as compared with MSW bottom ash is mainly due to the existing of more uniformly distributed particle size in the RDF bottom ash. However, the design strength of normal concrete mixes is 210 Kg/cm^2 in Taiwan. This implies that compressive strength of concrete mixes with the washed RDF bottom ash as fine aggregate presents about 23% lower than the designed compressive strength of concrete mixes with normal sand. Such outcomes would limit the reuse potential of RDF bottom ash in some construction programs.

CONCLUSIONS

In recent years, the public is concerned about the changing characteristics of incineration in response to the increase of heating values, incinerator emissions and ash properties. This paper specifically investigates the ash property and reuse potential from burning two types of wastes (MSW and RDF) as fuels. The TCLP tests reveal that the bottom ash generated from burning MSW and RDF can be classified as non-hazardous materials. But both types of fly ash require post-treatment due to higher content of heavy metals. To evaluate the reuse potential of those bottom ash, compressive strength tests were also conducted using washed bottom ash as fine aggregate in a normal mix at general water-cement ratio conditions. These data are useful in determining which applications may be better suited for different sources of ash. Final suggestions of reuse potential of bottom ash as fine aggregate in concrete mixing can be made based on the tested properties of compressive strength and workability. Test results indicate that mass burn of MSW may result in a lower ash reuse potential due to inhomogeneous mixes. Overall, the inclusion of waste sorting process prior to the incineration facilities can provide RDF with better quality to the mass burn process and higher reuse potential of RDF bottom ash may be attained. However, due to relatively lower compressive strength as compared with normal concrete mixing, the reuse potential of incineration ash is rather limited in some construction programs.

Acknowledgement

The authors acknowledge the financial support from the National Science Council (NSC-85-2621-P-006-033) and helpful comments of anonymous referees in the review process.

REFERENCES

1. Sommer, E. J., Kenny, G. R., and Roos, C. E., "Mass Burn Incineration with a Presorted MSW Fuel," Journal of Air & Waste Management Association, Vol. 39(4): 511-516 (1989).
2. Jackson, D. V., "Advances in Thermal Treatment and RDF," Resources and Conservation, 14:1-13 (1987).
3. Bunsow, W. and Dobberstein, J., "Refuse-derived Fuel: Composition and Emissions from Combustion," Resources and Conservation, 14:249-256 (1987).
4. Wilson, D. C., "The Efficiency of Resource Recovery from Solid Waste," Resource Recovery and Conservation, 4:161-188 (1979).
5. Eastman, R. M., "Quality Control in Resource Recovery," Resource Recovery and Conservation, 4:189-201 (1979).
6. Eley, M. H. and Guinn, G. R., "A New Processing System for the Production of Improved Refuse Derived Fuel and Recyclables from Municipal Solid Waste," in Proceedings of 1994 National Waste Processing Conference, 1994, Boston, Massachusetts, USA, 283-291.
7. Ferraro, F. A., "Results of Emissions and Ash Testing at a Modern Refuse-derived Fuel Plant," in Proceedings of Resource Recovery of Municipal Solid Waste, Knox, P. J., editor, AIChE Symposium Series, 1988, pp. 36-42.
8. Jackson, D. V.,"Advances in Thermal Treatment and RDF," Resources and Conservation, 14:1-14 (1987).

9.Kreiter, B. G., "The Effectiveness of Waste Treatment Systems," Resource Recovery and Conservation, 4: 203-207 (1979).
10.Sokol, D. L., "Refuse-derived Fuel Versus Mass-burn Technology: Ogden Martin's Haverhill/Lawrence, Massachusetts Projects," in Proceedings of Resource Recovery of Municipal Solid Waste, 1988, Knox, P. J., editor, AIChE Symposium Series, 30-35.
11.Sommer, E. J. Jr., Kenny, G. R., Kearley, J. A., and Roos, C. E.,"Mass Burn Incineration with Presorted MSW Fuel," Control Technology, 39(4):24-30 (1989).
12.Wilson, D. C., "The Efficiency of Resource Recovery from Solid Waste," Resource Recovery and Conservation, 4:161-188 (1979).
13.Tay, J. H. and Goh, A. T. C.,"Engineering Properties of Incinerator Residue," Journal of Environmental Engineering, ASCE, 117(2):224-235, (1991).
14.Poran, C. J. and Faouzi, A. A.,"Properties of Solid Waste Incinerator Fly Ash," Journal of Geotchnical Engineering, 115(8):1118-1132, 1989.
15.Levie, B., Sevy, D., Tormey, M. and Boughton, B.,"Ash Characterization of California MSW Incinerators," in Proceedings of 1994 National Waste Processing Conference, 1994, Boston, Mass., USA, 99-106.
16.Chesner, W. H., Collins, R. J., and Fiesinger, T.,"The Characterization of Incinerator Residue in the City of New York," in Proceedings of 1986 National Waste Processing Conference, 1986, 419-434, Denver, Colorado, USA.
17.Savage, G. M. and Diaz, L. F.,"Characteristics of RDF Ash," in Proceedings of 1988 National Waste Processing Conference, 1988, 139-144, Philadelphia, Penn., USA.
18.Richard, W. G.,"Engineering Evaluation of Resource Recovery Residue Utilization Modes," in Proceedings of the Second International Conference on Municipal Solid Waste Combustor Ash Utilization, 1989, Houston, Texas, USA 363-380.
19.Black, G. A. and Cunningham, J. C.,"Ash Block as a Utilization Product,"in Proceedings of the Fourth International Conference on Municipal Solid Waste Combustor Ash Utilization, 1991, Arlington, Virginia, USA 181-190.
20.Javed, I. B. and Kenneth, J. R.,"Light Weight Aggregates from Incinerated Sludge Ash," Waste Management & Research, 7:363-376 (1989).
21.Tay J. H.,"Energy Genration and Resource Recovery from Refuse Incineration," Journal of Energy Engineering, ASCE, 114(3):107-117 (1988)
22.Ali, M. T. and Chang, W. F.,"Strength Properties of Cement-stabilized Municipal Solid Waste Incinerator Ash Masonry Bricks," ACI Materials Journal, 91(3):256-263 (1994).
23.Yip, W. K.,"Aggregate made from Incinerated Sludge Residue," Journal of Materials in Civil Engineering, 2(2):84-93 (1990).
24.Aziz, M. A. and Ramaswamy, S. D.,"Incinerator Residue for Roads," Geotechnical Testing Journal, 15(3): 300-304 (1992).
25.Goh, A. T. C. and Tay, J. H.,"Municipal Solid Waste Incinerator Fly Ash for Geotechnical Applications," Journal of Geotechnical Engineering, 119 (5):811-825 (1993).
26.Lin, C. F. and Hsi, H. C.,"Resource Recovery of Wate Fly Ash: Synthesis of Zeolite-like Materials," Environmental Science & Technology, 29(4):1109-1116 (1995).

Table 1 ： TCLP analysis of bottom ash

	MSW	RDF	TCLP Standards
Pb(mg/L)	ND~ND<0.03	0.11~0.12	5.0
Cd(mg/L)	0.01~0.02	0.05~0.06	1.0
Cu(mg.L)	0.3~0.4	0.39~0.40	15
Zn(mg/L)	1.5~1.6	16.1~16.3	25
Cr(mg/L)	0.03~0.04	0.12~0.13	5.0
Hg(mg/L)	ND~ND<0.0002	ND~ND<0.0002	0.2
As(mg/L)	ND~ND<0.001	ND~ND<0.001	5.0
pH	11.8	10.2	—
Cr^{+6}(mg/L)	0.005~0.006	0.05~0.06	2.5
CN^{-}(mg/L)	ND~ND<0.002	ND~ND<0.002	—

Table 2 ： TCLP analysis of fly ash

	MSW	RDF	TCLP Standards
Pb(mg/L)	9.48~9.65	0.03~0.05	5.0
Cd(mg/L)	4.60~4.67	2.599~2.614	1.0
Cu(mg.L)	22.3~22.4	9.62~9.66	15
Zn(mg/L)	5.22~5.34	21.5~21.8	25
Cr(mg/L)	ND~ND<0.02	0.04~0.06	5.0
Hg(mg/L)	ND~ND<0.0002	ND~ND<0.0002	0.2
As(mg/L)	ND~ND<0.001	ND~ND<0.001	5.0
pH	5.6	5.0	—
Cr^{+6}(mg/L)	0.002~0.004	0.002~0.003	2.5
CN^{-}(mg/L)	0.002~0.003	ND~ND <0.002	—

Table 3 ： Chemical composition of ash

	MSW bottom ash	MSW fly ash	RDF bottom ash	RDF fly ash
CaO(%)	34.678	16.901	44.668	19.546
SiO_2(%)	18.653	12.481	19.861	20.186
Al_2O_3(%)	13.973	5.946	13.392	10.897
Fe_2O_3(%)	27.053	48.341	10.327	43.978
ZnO(%)	—	13.336	5.325	3.528
MgO(%)	5.492	—	4.577	1.590
Cr_2O_3(%)	—	2.926	1.836	0.164
total(%)	99.850	99.932	99.987	99.890

Table 4: Particle size distribution of RDF bottom ash

sieve no.	retained amount by weight (g)		accumulated amount by weight (g)		accumulated percent retained by weight(%)		accumulated percent passing by weight(%)	
	washed	unwashed	washed	unwashed	washed	unwashed	washed	unwashed
#4	50	50	50	50	5.38	5.03	94.62	94.97
#8	96	96	146	146	15.70	14.69	84.30	85.31
#16	156	156	302	302	32.47	30.38	67.53	69.62
#30	178	178	480	480	51.61	48.29	48.39	51.71
#50	146	146	626	626	67.31	62.98	32.69	37.02
#100	176	176	802	802	86.24	80.68	13.76	19.32
#200	128	128	930	930	100.00	93.56	0.00	6.44
residual		64		994		100.00		0.00

Table 5: Particle size distribution of MSW bottom ash

sieve no.	retained amount by weight (g)		accumulated amount by weight (g)		accumulated percent retained by weight(%)		accumulated percent passing by weight(%)	
	washed	unwashed	washed	unwashed	washed	unwashed	washed	unwashed
#4	56	56	56	56	6.35	5.81	93.65	94.19
#8	112	112	168	168	19.05	17.43	80.95	82.57
#16	96	96	264	264	29.93	27.39	70.07	72.61
#30	114	114	378	378	42.86	39.21	57.14	60.79
#50	104	104	482	482	54.65	50.00	45.35	50.00
#100	230	230	712	712	80.73	73.86	19.27	26.14
#200	170	170	882	882	100.00	91.49	0.00	8.51
residual		82		964		100.00		0.00

Table 6: Properties of normal sand, MSW and RDF ash

property	average or ranges		
	washed MSW bottom ash	washed RDF bottom ash	normal sand
fineness modulus	3.59	3.34	-
specific gravity	2.27	2.38	2.66
water adsorption (%) (at dry basis)	7.4	9	2.0
carbon content (%)	2.60~2.67	0.63~0.66	-

Table 7: Compressive strength of concrete mixes over different ages

choice of fine aggregate	age (day)	compressive strength (kg/cm^2)	
		ranges	average
normal sand	3	106.1~114.9	111.9
washed MSW bottom ash	3	44.2~70.7	58.9
washed RDF bottom ash	3	88.4~97.3	91.3
normal sand	7	150.3~185.7	167.9
washed MSW bottom ash	7	61.8~79.5	73.6
washed RDF bottom ash	7	70.7~128.2	107.5
normal sand	14	194.5~203.4	197.4
washed MSW bottom ash	14	88.4~114.9	106.1
washed RDF bottom ash	14	97.2~150.3	126.7
normal sand	28	221.1~274.1	241.6
washed MSW bottom ash	28	88.4~123.8	109.1
washed RDF bottom ash	28	132.6~176.8	156.2

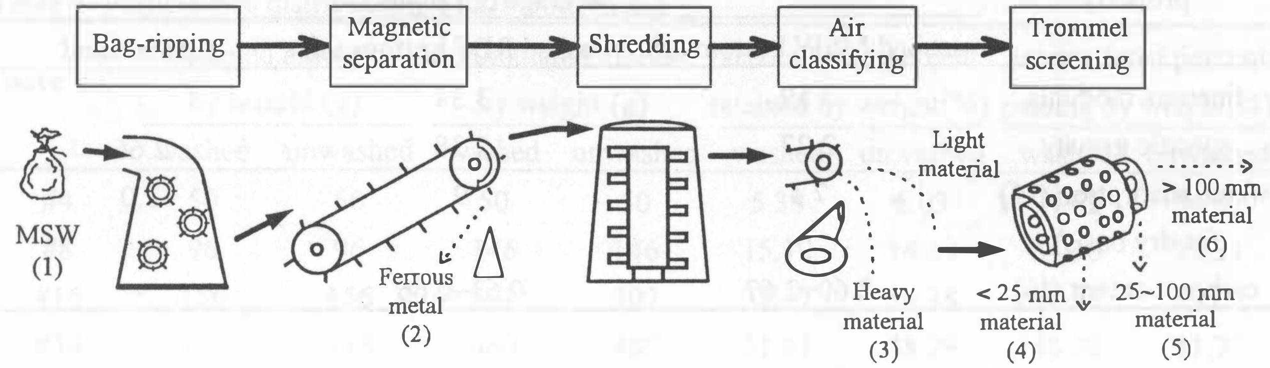

Figure 1: The system configuration of solid waste sorting process

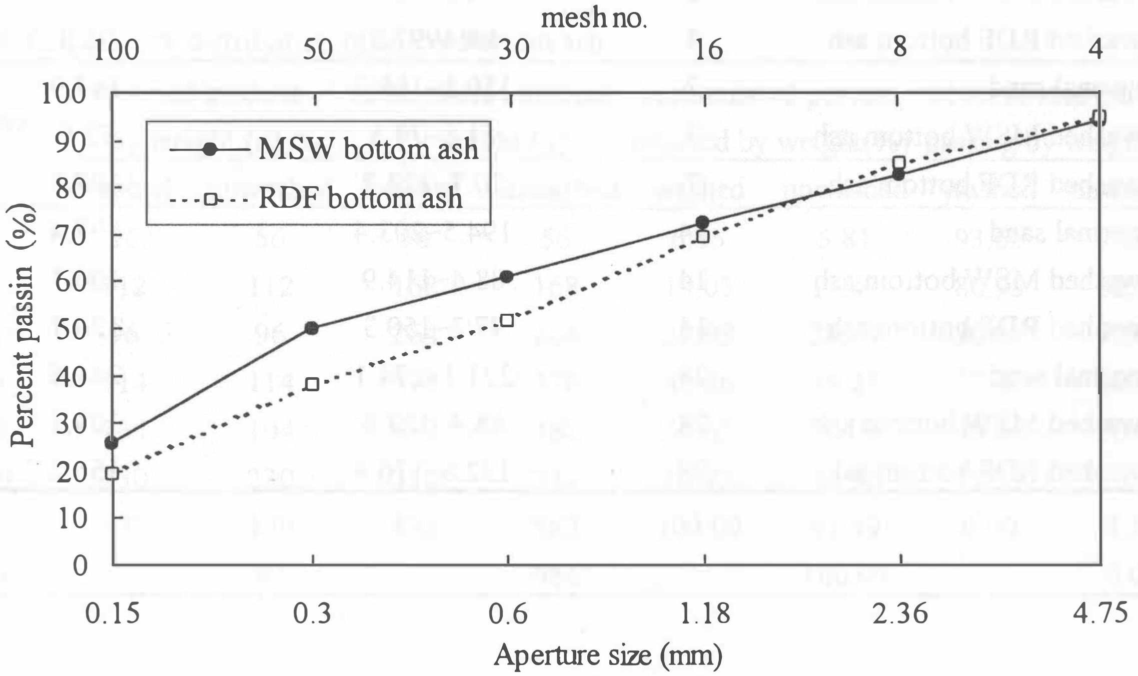

Figure 3: Grading of washed MSW and RDF bottom ash

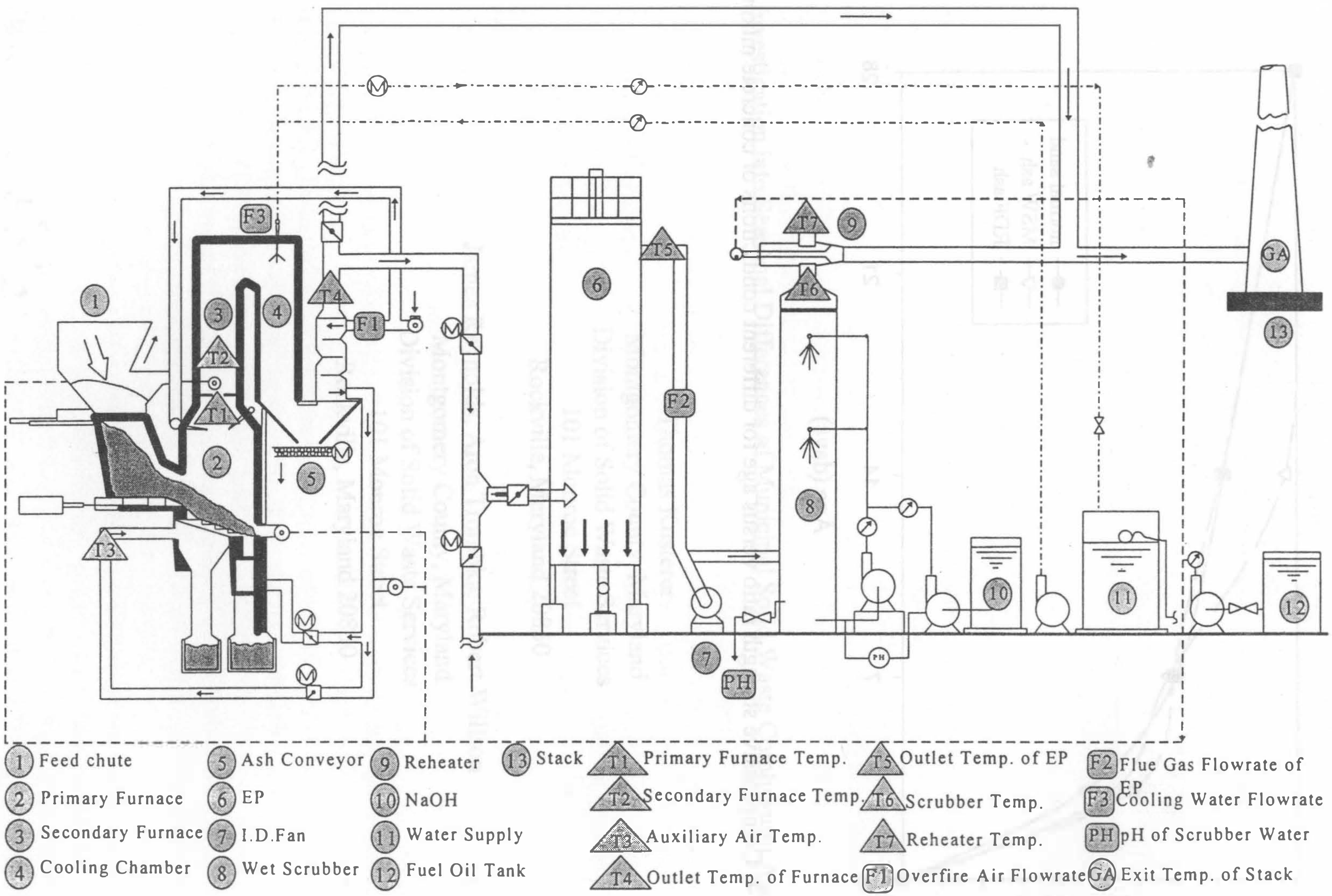

Figure 2: The system configuration of solid waste incineration process

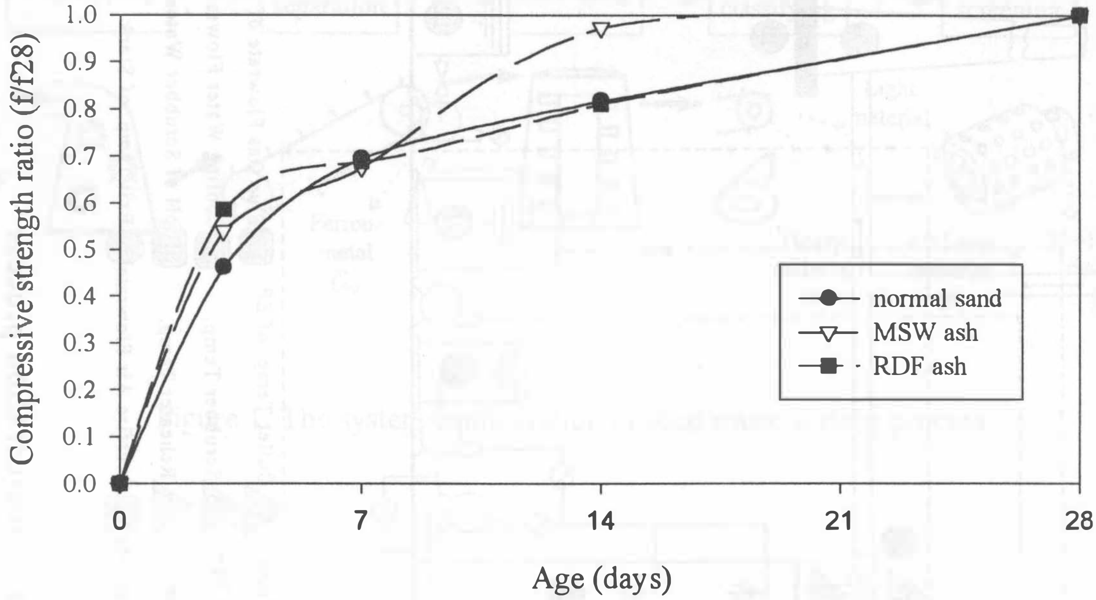

Figure 4: Compressive strength ratio versus age for different condictions of concrete mixing