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UTILIZATION OF MUNICIPAL SOLID WASTE INCINERATOR FLY ASH AS A PARTIAL AGGREGATE REPLACEMANT IN CEMENT MORTARS

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งานวิจัยนี้จัดทำขึ้นโดยมีวัตถุประสงค์เพื่อ ศึกษาการใช้ประโยชน์เถ้าลอยจากเตาเผาขยะมูลฝอยชุมชน จังหวัดภูเก็ต โดยนำมาทดแทนส่วนผสมของมวลรวมละเอียดเพียงบางส่วนในก้อนซีเมนต์มอร์ตาร์ โดยมีการทดสอบลักษณะทางกายภาพ และทางเคมีของเถ้าลอยอันได้แก่ ลักษณะการกระจายตัวของอนุภาค องค์ประกอบทางเคมี แร่องค์ประกอบ ปริมาณโลหะหนัก รวมถึงลักษณะน้ำชะ จากนั้นเถ้าลอยจะถูกนำมาสู่การบำบัดขั้นต้นโดยการล้างด้วยน้ำเพื่อกำจัดคลอไรด์ จากนั้นนำมาปรับเสถียรด้วยการทำให้แข็งด้วยปูนซีเมนต์ที่อัตราส่วนต่างๆ แล้วจึงบดให้ขนาดเล็กลงกลายเป็นมวลรวมละเอียดเทียมที่สามารถนำกลับมาใช้ใหม่ได้ ลักษณะของมวลรวมละเอียดเทียมได้รับการทดสอบเพื่อเปรียบเทียบกับมวลรวมละเอียดธรรมชาติหรือทราย กำลังรับแรงอัดของก้อนซีเมนต์มอร์ตาร์ที่ผสมด้วยมวลรวมละเอียดที่ทดแทนด้วยมวลรวมละเอียดเทียมเพียงบางส่วน ที่อัตราส่วนผสมต่างๆ จะถูกทดสอบที่ระยะเวลาการบ่มต่างๆ ท้ายที่สุดลักษณะน้ำชะจากก้อนซีเมนต์มอร์ตาร์ที่มีมวลรวมละเอียดเทียมผสมอยู่ ถูกทดสอบเพื่อศึกษาความปลอดภัยต่อสิ่งแวดล้อมและสุขอนามัยของประชาชน

การทดสอบลักษณะของเถ้าลอยพบว่า อนุภาคของเถ้าลอยมีขนาดเล็ก โดยเถ้าลอยที่พรมน้ำแล้วอนุภาคจะมีขนาดใหญ่กว่าเถ้าลอยแห้ง ปริมาณโลหะหนักในเถ้าลอยที่มีอยู่มีค่าไม่มากนัก เมื่อเปรียบเทียบกับองค์ประกอบอื่นๆ แต่มีความเป็นไปได้ที่จะถูกชะออกมากับน้ำชะเกินกว่าเกณฑ์ที่กฎหมายกำหนด จึงจัดเถ้าลอยเป็นของเสียอันตราย จากการบำบัดเถ้าลอยขั้นต้นพบว่า น้ำล้างเถ้าลอยมีปริมาณคลอไรด์และโลหะหนักปนออกมาในเกณฑ์ที่สูง ซึ่งสอดคล้องกับการทดสอบองค์ประกอบทางเคมี และแร่ของเถ้าลอย ผลการทดสอบมวลรวมละเอียดเทียมเทียบกับมวลรวมละเอียดธรรมชาติพบว่า เถ้าลอยที่ผ่านกระบวนการบำบัดขั้นต้นและการปรับเสถียร หรือที่เรียกว่ามวลรวมละเอียดเทียม มีศักยภาพในการใช้เป็นส่วนผสมหนึ่งในซีเมนต์มอร์ตาร์ โดยเมื่อทดสอบกำลังรับแรงอัดของก้อนซีเมนต์มอร์ตาร์ที่อายุ 28 วันพบว่า กำลังรับแรงอัดของก้อนซีเมนต์มอร์ตาร์ที่ผสมมวลรวมละเอียดธรรมชาติแล้วทดแทนด้วยมวลรวมละเอียดเทียมที่ผลิตมาจากเถ้าลอยพรมน้ำแล้ว ที่อัตราร้อยละ 20 มีค่าสูงที่สุดเมื่อเทียบกับก้อนซีเมนต์มอร์ตาร์ควบคุม และยังพบอีกว่า ค่ากำลังรับแรงอัดของกลุ่มก้อนซีเมนต์มอร์ตาร์ที่ผสมมวลรวมละเอียดธรรมชาติแล้วทดแทนด้วยมวลรวมละเอียดเทียมที่ผลิตมาจากเถ้าลอยพรมน้ำแล้ว ที่อัตราร้อยละ 10 เป็นกลุ่มที่มีค่าที่สูงเช่นกัน

ก้อนซีเมนต์มอร์ตาร์ที่ผสมด้วยมวลรวมละเอียดเทียมที่อายุ 28 วัน ถูกนำมาทดสอบหาปริมาณโลหะหนัก ผลการทดสอบพบว่า ปริมาณโลหะที่ถูกชะออกมากับน้ำชะ อยู่ในเกณฑ์ที่กฎหมายกำหนดตามค่าที่กำหนดไว้ในประกาศกระทรวงอุตสาหกรรม ฉบับที่ 6 (พ.ศ. 2540)

สาขาวิชา...การจัดการสิ่งแวดล้อม (สหสาขาวิชา)...ลายมือชื่อนิสิต...สุธีร์ ตราดธารทิพย์.....

ปีการศึกษา.....2548.....ลายมือชื่ออาจารย์ที่ปรึกษา.....

4789493220: MAJOR ENVIRONMEMTAL MAMAGEMENT
KEY WORD: FLY ASH / MUNICIPAL SOLID WASTE / INCINERATOR / STABILIZATION / SOLIDIFICATION / AGGREGATE / CEMENT MORTARS

SUTEE TRADTARNTIP : UTILIZATION OF MUNICIPAL SOLID WASTE INCINERATOR FLY ASH AS A PARTIAL AGGREGATE REPLACEMENT IN CEMENT MORTARS. THESIS ADVISOR : MANASKORN RACHAKORNKIJ, Ph.D., 91 pp. ISBN 974-14-3284-4.

The research was conducted to investigate characteristics of two types of municipal solid waste incinerator fly ash (MSWIFA); sprayed and non-sprayed, collected from a mass-burn incinerator in Phuket, Thailand. Solidified MSWIFA was applied to replace natural sand for producing MSWIFA cement mortars. The following physical and chemical characteristics were determined; particle size distribution, bulk chemical and mineralogical compositions, total heavy metals, and leached heavy metals. Preliminary treatment of MSWIFA was carried out for chloride reduction by washing. Then, the washed MSWIFA was mixed with cement in solidification and stabilization (S/S) process to produce recycled aggregate and then compared their properties with natural sand. Cement mortar specimens containing recycled aggregate were examined for developments of compressive strength. The recycled aggregate cement mortars were as well evaluated for impacts on environmental safety and public health.

The results showed that sprayed MSWIFA particles were bigger than those of non-sprayed MSWIFA. Although heavy metals from the both types were present in small amounts, concentrations of lead (Pb) and selenium (Se) exceeded the regulatory limits. From the preliminary treatment, it was found that high amount of chloride was dissolved in wash water. That was consistent with high chlorides determined in the chemical composition analyses. Comparison between recycled aggregate and natural aggregate showed that the recycled aggregates had a potential to be used as an admixture in concrete construction. Moreover, the development of compressive strength of cement mortar specimens at 28 days of curing age demonstrated that the compressive strengths of cement mortars containing 20 percent by weight of sprayed recycled aggregate was the highest. The group of specimens containing 10 percent sprayed fly ash possessed the highest strengths even when compared with control specimens.

The 28-day cement mortars containing recycled aggregates were investigated for leachate characteristics by extraction procedure described in the Notification of Ministry of Industry No.6 B.E.2540 (1997). The results showed that the concentrations of heavy metals in the leachate of all specimens met the regulatory limits.

Field of study..Environmental Management..Student's signature..Sutee Tradtarntip

Academic year.....2005.....Advisor's signature.....

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Finally I would like to dedicate this thesis with due respect to my beloved parents, sister, and relatives for their wholehearted understanding, constant encouragement, patient support, love, and inspiration throughout my entire study.

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LIST OF ABBREVIATIONS

MSW	=	Municipal Solid Waste
MSWI	=	Municipal Solid Waste Incineration
MSWIFA	=	Municipal Solid Waste Incinerator Fly Ash
SFA	=	Sprayed Fly Ash
FA	=	Non-sprayed Fly Ash
PCD	=	Pollution Control Department
LOI	=	Lost on Ignition
APC	=	Air Pollution Control
L/S	=	Liquid-to-solid Ratio
TFA	=	Treated Fly Ash
C-S-H	=	Calcium Silicate Hydrate
ASTM	=	American Society for Testing of Materials
TCLP	=	Toxicity Characteristic Leaching Procedure
SPLP	=	Synthetic Precipitation Leaching Procedure
XRF	=	X-ray Fluorescence Spectroscopy
PSD	=	Particle Size Distribution
PSA	=	Particle Size Analyzer
S/S	=	Stabilization and Solidification
RA	=	Recycled Aggregate
SRA	=	Sprayed Fly Ash Recycled Aggregate
FRA	=	Non-sprayed Fly Ash Recycled Aggregate
TIS	=	Thailand Industrial Standards
MOI	=	Ministry of Industry
ksc	=	Kilogram per Square Centimeter
MXX	=	Cement Mortars at XX % of Recycled Aggregate Replacement to Natural Sand

CHAPTER I

INTRODUCTION

1.1 General

Municipal solid waste (MSW) is one of major problems in all cities, especially in big cities that have large populations. The more populations there are the more MSW is generated. For centuries, landfill is the most common way to manage MSW problems as yet, either normal pit or sanitary landfill, since it is the easiest and cheapest technique in view of construction and management. However, the problems remain, not only on the limitation of space for construction of landfill sites but also on potential environmental impacts; for example, odor, infectious diseases, and toxic landfill leachate. Therefore, management of MSW by landfill can be a significant problem issue nowadays. Incineration of MSW has become an viable management alternative that is popular, both in the United States and many European countries for decades now. Although incineration could reduce 70-80 percent by volume of MSW, there are residues left to be handled, bottom ash and fly ash from the combustion process and air pollution control devices. These ashes are usually contaminated with heavy metals. The usual practice is to dispose of these ashes in a secure landfill. This could pose a potential threat to groundwater contamination by toxic leachates as well. Consequently, these residues must require proper management.

Incineration is a frequently adopted solution for managing the increase of MSW quantity. MSW incinerator could be divided into two major types; namely, refuse-derived fuel (RDF), which involves pre-sorting of MSW to remove glass and ferrous items before being fed into the incinerator, and mass-burn, in which MSW is directly fed without sorting. The incinerator in Phuket, Thailand, which has been in operation since 1998 is a mass-burn type. Though the incinerator can reduce the

volume of MSW and provides energy, it is not an ultimate solution as it generates ashes that must be subsequently disposed. Bottom ash leaves from the incinerator at the base of combustion chamber and consists of a slag-type material while fly ash is separated from flue gas by the air pollution control devices. In addition, fly ash consists of fine particles that contain leachable heavy metals, and is thus classified as a hazardous waste. In year 2004, MSW was collected to incinerate at the Phuket municipal solid waste incinerator up to 336 tons per day; however, only approximate 244 tons was incinerated per day. As a result, the remaining MSW and residues (non-combusted), bottom ash, and fly ash, were dumped into landfill in the amount of 92, 53, and 5 tons per day, respectively. That means all of residues were disposed into landfill approximately 44 percent of MSW weight.

Disposal of MSWIFA into ordinary landfill sites causes severe environmental problems, principally because this material contains high concentrations of leachable heavy metals. There have several technologies which have been investigated in order to reduce the hazardous characteristics of MSWIFA.

At present, the incineration ash management has been under investigation so as to encourage recycling and reusing to produce new valuable product. Especially fly ash, classified as a hazardous waste, is not suitable for disposal in ordinary landfill. Fly ash has more elements and compounds (such as metals and salts); hence, there is a potential for use as raw materials. Many researchers have used fly ash in many different ways; the use of raw material with non pre-treatment and pre-treatment. There are many potential applications for fly ash; for instance, construction materials, geotechnical, agriculture, and miscellaneous (such as sorbent and sludge conditioning).

The most widely recent applied technique to manage the ashes from the incinerator is a process of stabilization and solidification using Portland cement or other inorganic agents, i.e. powdered blast furnace slag and calcium sulphate. For the reason that, the hazardous material could be encapsulate with cement hydration. Hence, it would reduce the harmfulness to the environment.

In this study, municipal solid waste incinerator fly ash (MSWIFA) was used as recycled aggregate produced by stabilization/solidification process by mixing cement with MSWIFA. Relationship between required cement content and amount of MSWIFA that produce leachate contained heavy metals within acceptable limits will be examined. After that the physical properties of recycled aggregate were determined for various ratios between cement and recycled aggregate and compared with natural fine aggregate (sand). The compressive strengths were determined later on cement mortar specimens that incorporated recycled aggregate, following the standards issued by Thailand Industrial Standards Institute, Ministry of Industry, TIS 15 Part 12-2532 (1989): Portland cement Part 12 Test method for compressive strength of hydraulic cement mortars. Furthermore, heavy metal concentrations in leachates from those cement mortars were investigated according to the leachate extraction procedure described in the Notification of Ministry of Industry No.6, B.E. 2540.

1.2 Objectives

The main objective of the study is to investigate utilization of municipal solid waste incinerator fly ash (MSWIFA) by mixing with Portland cement in stabilization and solidification process and using it as recycled aggregate to replace natural aggregate in cement mortars. The specific objectives are as follows:

1. To determine characteristics of the MSWIFA
2. To determine characteristics of the recycled aggregate
3. To determine properties of the cement mortars incorporating MSWIFA as partial aggregate replacement material
4. To evaluate the potential environmental impact from stabilized and solidified product of MSWIFA

1.3 Scopes of the Study

This research is aimed to determine the possibility of fly ash utilization in term of compressive strength development and leachate characteristics of cement mortars containing MSWIFA. The fly ash was collected from the municipal solid waste incinerator facility, a mass-burn incinerator with pre-sorting MSW plant, in Phuket, Thailand.

The following tasks of the research were carried out.

1. Study of the characteristics of MSWIFA sampled during June 16-17, 2005
2. Determination and design of ratio of MSWIFA and cement in Stabilization and Solidification process to produce the recycled aggregate.
3. Study of the properties of recycled aggregate in comparison with natural fine aggregate (sand)
4. Investigation of the compressive strength of cement mortars containing natural aggregate that is partial replaced by recycled aggregate
5. Investigation of heavy metals in leachates via the method described in the sixth Notification of Ministry of Industry B.E. 2540 (1997) from cement mortars.

CHAPTER II

LITERATURE REVIEW

2.1 Municipal Solid Waste

In 2004, Thailand's municipal solid waste increased. The total amount of solid waste around the country, (excluding the amount of solid waste not being dropped into the bins), was approximately 14.6 million tons per year or 39,956 tons a day, increasing about 0.2 million tons from the previous year. Only in the Bangkok Metropolitan area, the amount of collected solid waste was 9,356 tons while the amount of solid waste generated in the municipal area and Muang Pattaya was 12,500 tons a day. The amount of waste generated in other non-municipal areas, covering all Tambon Administration Organization areas, was 18,100 tons a day. The growing percentage of solid waste generated from 2003 to 2004 was 1.82. The rising amount of solid waste can come from the population growth, expansion of communities, governmental economic stimulus, tourism promotion and development.

In city or municipal areas, solid waste was generated 12,500 tons a day, which would be treated by the waste eradication pursuant to public health principles, in 106 facilities: 103 sanitary landfill facilities and 3 incinerators (Lampoon, Phuket, and Tambon Koh Samui Municipality). 5,325 tons of solid waste or 42.6 percent from all municipal areas around Thailand could be wiped out per day by these facilities. However, the residue waste has not yet been treated properly proved by the existence of open dumping and open burning. Moreover, most sanitary landfills still encountered a number of problems, including improper operation system and maintenance, shortage of skilled and experienced personnel in the operation system, as well as shortage of budgets for maintaining and running the operation system (PCD, 2005).

In the year 2004, MSW was collected to incinerate at the Phuket municipal solid waste incinerator up to 336 tons per day. However, only approximate 244 tons was incinerated per day. As a result, remaining 92 tons of MSW and residues, 53 tons of bottom ash and 4 tons of fly ash were dumped into landfill daily. This means that all of residues were disposed into landfill approximately 44 percent of total MSW weight.

According the mentioned figures, there are high amount of residues due to an overload of incinerator's design and ash residues. The waste utilization is the appropriate alternative way to manage these residues in order to reduce landfill site to dispose and to decrease the problems from landfill operation, i.e. leachate contained heavy metals. In other words, the utilization of these residues would be actual final disposal of waste.

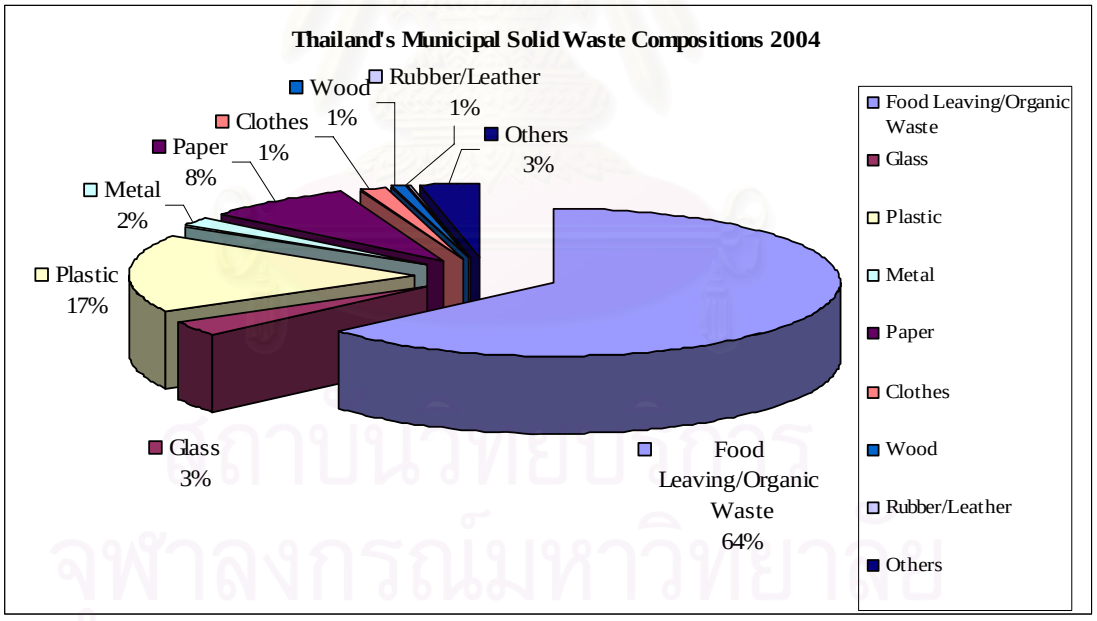

Figure 2.1 Thailand's Municipal Solid Waste Compositions 2004

Source: Pollution Control Department (PCD), Ministry of Natural Resources and Environment, Thailand State of Pollution Report 2004

2.2 Utilization of Municipal Solid Waste Incinerator Fly Ash

In the present, municipal solid waste incinerator fly ash (MSWIFA) was used in various applications. There are a lot of studies MSWIFA. Many researchers pay attention to study on MSWIFA utilization because MSWIFA are generated all the time, as mentioned in chapter one. Also, they have found that MSWIFA has some potential which could be used as raw material in civil and environmental engineering fields. Moreover, it could solve the recent environmental problems such as the limitation of landfill site for disposal, groundwater contamination by the leakage leachate containing heavy metals and it would be verily final disposal.

Environmental considerations are increasingly affecting the supply of aggregate. There are strong objections to opening pits as well as to quarrying. In Thailand, they usually proceed the fine aggregate from the base of river. It makes the banks of river destroying. At the same time, there are problems with the disposal of construction demolition waste and with dumping of domestic waste. Both types of waste can be processed into aggregate for use in concrete (Neville, 2003). As far as the use of domestic waste is concerned, the incinerator ash, after the removal of ferrous and non-ferrous metals, can be ground to fine powder, blend with clay, palletized and fired in a kiln to produce artificial aggregate.

The possible applications for municipal solid waste incinerator fly ash were currently focused on the reuse of MSW fly ash and identify the new potential uses. There are several applications that were identified and grouped into four main categories: construction material, geotechnical application, agriculture, and miscellaneous use (such as sorbent and sludge conditioning). Each application is invented by analyzing the final-product technical characteristics and the environmental impacts. The information of the study is systemized for the selection of best technology and final products of MSW fly ash. The study also shows the new possibilities for MSW fly ash reused in a short-term, in a wide range of fields, resulting in great advantages in waste minimization as well as resources conservation. Three main factors are considered relevant to evaluate MSW fly ash suitability for

each application: suitability for processing, technical performance and environmental impact. The MSW fly ash has encouraged the recycle and reuse in many application because it is rich in some elements and compounds, such as metals and salts. Therefore, it has some potential to be used as raw material in construction. MSW fly ash has potential application in concrete product, either as a replacement of cement or as an aggregate. Use of MSW fly ash in concrete as aggregate is one option of application in concrete product. MSW fly ash could be used in addition to the finer fraction of the sand, a more promising use in lightweight concrete as a substitute of commercially available lightweight aggregates. Lightweight concrete is less dense than gravel concrete, but also has lower compressive strength. It presents improved thermal and sound insulation properties, which makes it appropriate for non-structural applications; for instance, the interior of walls for insulating purposes. It can also be used for structural applications, providing compressive strength, via the density and water absorption values are adequate. MSW fly ash could be processed into pellets and used as lightweight aggregate. The resulting product could be suitable for non-structural applications such as described above (Ferreira et al., 2003).

2.3 MSWIFA Characteristics

Fly ash resulting from municipal solid waste incineration (MSWI) is classified as a hazardous waste by the Italian legislation on solid waste disposal, owing to its heavy metals (Mangialardi, 2002)

In Thailand, the fly ash from MSWI is also classified as the hazardous waste because of its leachate contained high concentration of the heavy metals. Consequently, it need to proper disposal management. It could be not dumped in the sanitary landfill. The secure landfill which has specific protected design for leakage of leachate to groundwater is constructed for MSWI disposal but it needs the careful monitor in the long run as well as high investment and maintenance cost.

The ash residues from municipal solid waste incinerator are bottom and fly ashes. The investigation from Greenpeace Research Laboratories reveals that the bottom ash and fly ash residues arising from Phuket municipal solid waste incinerator contained high levels of the toxic heavy metals, including lead, copper, and cadmium (with lead present at over 0.1% by weight of the ash). The results of their study demonstrate the hazardous nature of the solid wastes generated by incineration of municipal solid waste. Toxic heavy metals are present in MSW ash residues as a result of their continued use in wide range of commercial and consumer products. The incineration does not destroy these metals, but simply disperses them via the incinerator stack and concentrates them into bottom and fly ash residues (Labunska et al., 2000).

Fucco et al. (2005) revealed their study on the Innovative stabilization/solidification processes of fly ash from an incinerator plant of urban solid waste that the raw residues, fly ashes, have high concentrations of trace metals, copper, lead, and cadmium. Especially concentration of Cd and Pb was higher than the corresponding regulatory limit. Therefore, the leachate from the residues shows the high concentration of Cd, Pb, and Cu too.

Table 2.1 shows the chemical composition from chemical analysis. The major element or chemical compound compositions are oxides of calcium (CaO), aluminium (Al_2O_3). High amount of calcium oxide (CaO) in MSWIFA are caused by the residues from air pollution control system (APC) because of excess dry lime which was injected into flue gas stream reacts with acid gases to produce harmless various salts. By the way, another major composition is chloride compound. Owing to high amount of chloride, it should not be allowed use of MSWIFA in reinforced concrete since chloride might lead to steel corrosion.

Table 2.1 Chemical Compositions of MSWIFA, and Coal Fly Ash

Compound Formula	MSWIFA	Washed MSWIFA	Mae-Moh CFA[1]
Al_2O_3	2.08	4.90	26.43
CaO	34.36	44.38	7.61
Cr_2O_3	0.00	0.03	-
CuO	0.05	0.07	-
Fe_2O_3	0.68	1.23	10.71
K_2O	5.27	0.65	3.07
MgO	1.30	4.12	2.21
MnO	0.03	0.08	-
Na_2O	3.70	1.53	1.11
PbO	0.15	0.23	-
P_2O_5	0.95	2.60	-
SiO_2	5.88	8.55	46.25
SnO_2	0.13	0.27	-
SO_3	4.15	7.93	1.85
SrO	0.04	0.05	-
TiO_2	0.39	0.83	-
ZnO	0.58	0.76	-
Br	0.00	0.00	-
Cl	27.80	4.48	-
Rb	0.00	0.00	-
LOI	12.44	17.33	0.23
Total	**100.00**	**100.00**	**99.47**

Source: Sancharoen (2003); "-" means does not reported.

2.4 Pre-Treatment of MSWIFA with Washing Process

Sancharoen (2003) studied the Utilization of Municipal Solid Waste Incinerator Fly Ash as a Partial Cement Replacement in Concrete. He worked on comparing between effect of use MSWIFA and washed MSWIFA substituting cement in concrete. The MSWIFA was washed by tap water two times in cement mortar mixer with a liquid-to-solid ratio (L/S) equal to 5. The mixer was run for 10 minutes then supernatant was removed and replaced with fresh water in the same L/S ratio.

The completely decanted MSWIFA was dried in an oven at 110°C until it is fully dry. However, the dried MSWIFA formed cake from the oven which needed to be simply ground by hand to be powder size. The results shown the MSWIFA highly consisted of chloride. On the other hand, the concentration of barium, lead, and chloride in wastewater from the washing process were higher than effluent standards.

Aubert et al. (2004) studied the Use of Municipal Solid Waste Incineration Fly Ash (MSWIFA) in Concrete. This study was worked on the development of a new physicochemical treatment for MSWIFA; they called “Revasol process”. MSWIFA was chosen among 10 incineration facilities that operate in Europe; because it was very rich in heavy metals. These fly ashes were treated according to three steps: Water dissolution of fly ash; to prevent the dissolution of heavy metals, Phosphation with phosphonic acid; to stabilize heavy metals, Calcination; to eliminate organic compounds, especially dioxins. The influence of treated fly ash (TFA) substituting in concrete has been evaluated in three characteristics: compressive strength, physical properties (durability) of hardened concrete, and its leaching behavior. Afterward, concrete was made by five different mixtures to compare TFA with cement and sand through five mixtures; a reference concrete (R), A12 and A15 in which cement was replaced by TFA at 12.5 and 50 percent, respectively, and finally, two compositions S12 and S50 in which 12.5 and 50 percent of cement were replaced by sand. The result of the substitution of TFA in place of cement in concrete does not involve a loss of mechanical strength greater than that caused by the reduction in the quantity of cement (TFA behaves like inert fine sand). Furthermore, the physical properties of both fresh and hardened concrete are not deteriorated by TFA replacement.

Mulder (1996) had studied in Pre-Treatment of MSWI Fly Ash Useful Application. The researcher aimed to find useful application of MSWIFA, after treatment, as a road construction material. A combination of a slight washing step and a stabilization/solidification step with cement and other additives appeared to be convenient in order to meet the standard. The slight washing step could removes more than 90% of Cadmium and Chloride that were originally present. Moreover, over 50% of Zinc and Sulphate are removed. The remaining solid material could be easily

processed into bound road foundation layer by adding 20% cement and other additives. However, the costs of the combination process: washing, processing of liquor and stabilization, equal the costs for disposal of MSWIFA.

Collivignalli and Sorlini (2002) treated the municipal solid waste incinerator fly ash (MSWIFA) via washing process before use. This process can reduce sulphate and chloride contents, that can cause expansion and corrosion problems in concrete structure. Washing treatment was made by mixing MSWIFA with water for 20-30 minutes with a liquid/solid ratio of 10 by weight. After 24 hours of waiting, the MSWIFA was settled. Then the surnatant was removed for water. Finally, the MSWIFA was dried at temperature equal to 105°C in the oven.

Derie (1996) treated a sample of MSWIFA by putting it in contact with water, in the solid/water ratio 1:10, the alkali chlorides, together with some calcium, magnesium, zinc, lead, and cadmium salts, rapidly dissolve at first. The pH was then close to seven but, if the contact was maintained between the solid and solution, it increased gradually, due to the slow hydrolysis of the aluminosilicates of the ash, and the liberation of calcium hydroxide. This caused the precipitation of Zn, Pb, and Cd hydroxides and, once the pH was achieved a value of about ten, the concentrations of these elements in the solution have decreased to a very low level.

2.5 Stabilization and Solidification

Stabilization and Solidification are physicochemical processes which have been broadly applied in the management of hazardous wastes. Stabilization is a process where additives are mixed with waste to decrease the rate of contaminant migration from and to reduce the toxicity of the waste. Similarly, solidification is a process which blends additives, such as cement, with the waste to create solidified form. The solidified state can achieve the engineering properties, for example, the compressive strength and also acquire low permeability. Therefore, stabilization and solidification would cover both the lessening in waste toxicity and mobility in

addition to an improvement in the engineering properties of stabilized and solidified waste.

The hydraulic binders most often used for waste stabilization/solidification are Portland cement, blast furnace slag cement, cement industry flue dust, coal fly ash and other wastes of pozzolanic nature in the presence of lime, calcium aluminates or often a mixture of several binders. Hydraulic binders mainly consist of oxides of calcium, silicon, aluminium, iron, magnesium, sodium, potassium and so on. Also, Calcium suphalte is added for control setting. The binders acquire a solid porous structure by hydration to give rise simultaneously to both solidification and physicochemical stabilization of the wastes (van der Sloot et al., 1998)

Cement-base stabilization is one of ordinary technique widely used to solidify hazardous materials. Solidifying materials by mixing with cement is the simplified and effortless method. Calcium hydroxide [$Ca(OH)_2$] in cement reacts with silica to form insoluble calcium hydrosilicates (C-S-H) with a considerable capacity to immobilize hazardous substance, especially heavy metals and to reduce the permeability of cement product. While the reaction (hydration)is occuring, the pH value raises into base state, causing insoluble form of heavy metals and reducing leachability too.

Collivignalli and Sorlini (2002) did the stabilization and solidification process for MSWIFA prior to use as material admixture in concrete product. The process was done by mixing washed MSWIFA with Portland cement, lime, sodium silicate, bentonite, blast furnace, and water. Portland cement causes the stabilized waste solidification; lime causes metal precipitation and keeps pH at the optimal value for metal leaching minimization; sodium silicate improved the solidification process and the stabilized waste mechanical properties; bentonite and blast furnace slag improved metal fixation in the stabilized waste and minimize their leaching. The stabilization and solidification process was made up of waste homogenization.

Mulder (1996) created the combination of a slight washing step and a stabilization/solidification step with cement and other additives. The MSWIFA passed these two processes could be easily developed into bound road foundation layer by adding 20% cement and other additives.

Derie (1996) studied a new stabilization technique for fly ash from municipal incinerators. The present general trend is not only to stabilize chemically the ashes, such as reducing the leachability of the toxic substances, but also to stabilize them mechanically like converting them in to massive, resistance, and unleachable solids. The stabilization technique was taking place in four stages: dissolution was made to eliminate the alkali chlorides; addition of a moderate quantity of phosphoric acid; calcinations; and solidification with Portland clinker or cement. The fly ash was mixed with about ¼ of its weight of Portland cement clinker, and hydrating for a few days in humid atmosphere. The result of massive solid possesses satisfactory mechanical properties.

He also suggested the general guidelines for the selection of a stabilization method based on the three assumptions. First, highly soluble salts (alkali chlorides mainly) must be removed. Second, toxic metals, mainly Cd and Pb, must be converted into poorly soluble and no reactive compounds. Last, the highly toxic polychlorodibenzodioxins and polychlorodibenzofurans must be destroyed.

2.6 MSWIFA as Admixture in Construction

Promthong (2003) had been studying the Effects of Solids Waste Sorting of Phuket Municipal Solid Waste Incineration Plant on Solidification of Fly Ash. This study is aimed to study the changes in fly ash properties before and after sorting of incoming MSW streams at the incineration plant, Phuket, Thailand. The physical and chemical characteristics of both types of fly ash were studied: ratio of fly ash to cement, ratio of water to binder, and curing times of specimens. The results showed that it could not be classified as a pozzolanic material according to ASTM C618. The

optimal recipe and condition found were than used in production of concrete masonry using both types of fly ash to partially replace cement and the cost of product was also estimated. Both types of fly ash were then used to partially replace cement in fly ash-cement mortars with a binder-to-sand ratio of 1:2.75. The highest unconfined compressive strength of fly ash-cement mortars was found at 30% of cement replaced and a water-to-binder ratio of 0.50. The fly ash-cement mortars have relatively lower compressive strength at any curing age compared with the control cement mortar. The 28-day unconfined compressive strength of hollow load-bearing fly ash-concrete masonry using both types of fly ash was 58% and 51% of the control, respectively. For sorted fly ash, the Chloride was decreased.

Inthasaro (2002) had been studying the Utilization of Municipal Solid Waste Incinerator Fly Ash as a Partial Cement Replacement. This study investigated the physical properties, chemical and mineralogical compositions of MSWIFA collected from mass-burn incinerator. The results indicated that MSWIFA could not be classified as a pozzolanic material according to ASTM C618 requirements. MSWIFA was used to replace cement for making fly ash-cement mortars. Then the mechanical properties of MSWIFA cement mortars were investigated such as compressive strength. The results showed slightly compressive strengths and longer setting times as well as required more water to obtain normal consistency than the control cement mortar. MSWIFA can be used to directly replace Portland cement up to 15% by weight with a 1:2.75 ratio of binder to sand and water to binder ratio of 0.485:1. The 28-day unconfined compressive strength of the optimum mortar mix possessed satisfactory strength of about 90% of the control.

Sancharoen (2003) had been studying the Utilization of Municipal Solid Waste Incinerator Fly Ash as a Partial Cement Replacement in Concrete. This research was studied on using of MSWIFA replacing in concrete mixtures. Fly ash was studied both physical and chemical properties comparing the cement properties that refer to ASTM C618. The experiment was designed to produce concrete that Portland cement was partially replaced by MSWIFA at 0, 10, 15, and 25 percent and washed-MSWIFA 15 percent by weight. The physical and chemical properties of

concrete investigated are slump value, setting time, unit weight, development of compressive strength and water-soluble chloride content. The results showed that the setting time of MSWIFA concrete reduced with increasing MSWIFA content; because of high content of chloride in MSWIFA. At the 10 percent MSWIFA replacement, MSWIFA concrete showed at the highest compressive strength that was 86 percent comparing to control concrete. However, all level of replacement gave the compressive strengths lower than the control concrete. The water-soluble chloride contents of MSWIFA concrete were within the limit preventing corrosion of reinforcing steel; nevertheless, MSWIFA highly consisted of chloride.

Collivignalli and Sorlini (2002) studied the reuse of Municipal Solid Waste Incineration Fly Ashes in Concrete Mixtures. The municipal solid waste incinerator fly ash (MSWIFA) was pretreated before use. The stabilization and solidification process was done by mixing washed MSWIFA with Portland cement, lime, sodium silicate, bentonite, blast furnace, and water. Portland cement causes the stabilized waste solidification; lime causes metal precipitation and keeps pH around the optimal value for metal leaching minimization; sodium silicate improves the solidification process and the stabilized waste mechanical properties; bentonite and blast furnace slag improves metal fixation in the stabilized waste and minimizes their leaching. The stabilization/solidification process was made up of waste homogenization. After that, waste milling, the stabilized waste were grinded to reduce interference on concrete mechanical quality. Last, the different concrete mixtures were produced by a partial replacement of natural aggregate with stabilized fly ashes. This study showed that the MSWIFA, which was reused as construction materials, could present an interesting alternative to final disposal. Although the compressive strength of concrete product was lower than that of the normal product, but it could be accepted by requirement for structural concrete.

2.7 Leaching Test and Extraction of Solidified Waste

Due to the environmental concerns, the leaching and extraction procedures are applied to study the mobility of toxic and hazardous matter which might be leaked from stabilized and solidified materials as well as to analyze the leachabilty of substance from other materials in various objectives.

Leaching is a method to remove soluble components from a solid matrix (Kim, 2005). Leaching can be described by the below very simple equation:

$$\text{material (leachee)} + \text{leachant} \rightarrow \text{leachate.}$$

It can be supposed that the material to be leached is known, although its physical and chemical/mineralogical properties will affect the final result. The purpose or what we expect to find in the leachate will determine the selection of leachant and also the conditions of the test.

Several common leaching testes are regulatory methods, mandated to characterize materials; others are approved by organizations for establishing compliance to particular specifications. Some methods are intended to mimic natural conditions or to obtain information about the nature of the extractable material within particular solid. The methods vary in the mass and particle size of the sample, the type and volume of leachant solution, the leachant delivery method, and time. Most procedures are carried out at ambient temperature. It also depends on the pH and composition of the leachant, the solubility of the chemical compound, and surface area of the solid. Although many methods were developed for application to municipal solid waste or industrial wastes, most leaching methods have been applied to a diversity of materials.

There are more than one hundred leaching methods, but there is no agreement on which method is the most appropriate to estimate the environmental effect of the use or disposal of MSWIFA utilization. Methods can also be classified as batch

leaching in which the sample is placed in a given volume of leachant solution, as column or flow through systems, and as bulk or flow around systems for monolithic samples.

Several leaching procedures are available to evaluate metals mobility. Two of the more frequently used procedures require that solid waste be mixed with the appropriate extraction fluid and agitated for 18 hours in a rotary agitator. The liquid is filtered, acid digested on a hot plate, and analyzed for metals by Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES). The most commonly used is EPA Method 1311, the Toxicity Characteristic Leaching Procedure (TCLP). This method evaluates metal mobility in a sanitary landfill. TCLP is the only leaching procedure approved for characterizing hazardous waste under RCRA. And EPA Method 1312, the Synthetic Precipitation Leaching Procedure (SPLP) is used to evaluate the potential for leaching metals into ground and surface waters. This method provides a more realistic assessment of metal mobility under actual field conditions, i.e. what happens when it rains. The extraction fluid is intended to simulate precipitation. The SPLP is a method of alternative when evaluating fate and transport of heavy metals in a suitably engineered waste land disposal facility from which municipal solid waste is excluded.

Many researchers have been using leaching test to examine the movement of toxic elements from stabilized and solidified material or extract heavy metals from specimen. They used standard and adapted methods in their researches.

Ferreira et al. (2003) manifested the impact to the environment of the application of lightweight, artificial aggregate. Since, the heavy metal leaching is not significant as long as the lightweight aggregate mixed in concrete is used under the encapsulated condition, as in internal structure. Even so, a problem could arise after the demolition of the structure, a situation where rainfall, acid rainfall, is expected to come in contact with fly ash, resulting in metal leaching.

Table 2.2 Characteristic Parameters of Static Batch Leaching Methods

Method	Leachant	Sample size, g	pH	L/S*	Time, hr
ASTM D-3987	Water	70		20	18
EPTOX	Water	100	5.0	20	24
SPLP	Water acidified with nitric and sulfuric acids	100	4.2	20	18
TCLP	Acetic Acid or Acetate Buffer	100	2.88	20	18
CA WET	0.2 M sodium citrate	50	5.0	10	48
LEP	Water acidified with 0.5 N acetic acid	50	5.0	16	24

Source: Kim (2005); *L/S: Liquid to Solid ratio, L/kg

The study by Aubert et al. (2004) the leaching behavior of treated fly ash (TFA) concrete confirmed that the process made it lower than the threshold values allowed for leachates from MSWI bottom ash to be reused in road works in France.

Mulder (1996) found the way to useful application of MSWIFA as a road construction material, after slight washing process and the stabilization/solidification of MSWIFA with cement. The result showed that the leaching characteristics of stabilized material meet the standard of future Building Materials Decree in The Netherlands.

Promthong (2003) studied the heavy metal concentrations of both fly ash leachates, before and after sorting of incoming MSW streams to incinerated process, were within the standards. Though, the lead concentration was significant for concerning. Also, amount of all heavy metals in leachates of both fly ash-concrete bricks met the regulatory limits.

Inthasaro (2002) studied the concentrations of heavy metals contained leachate by leaching test following the leachate extraction procedure described in the Notification of Ministry of Industry No.6, B.E. 2540 (1997). The results confirmed that all heavy metals in leachates of both MSWIFA and solidified MSWIFA products met the regulatory limits.

Sancharoen (2003) studied the leachate of MSWIFA and MSWIFA concrete products. The leachate extraction procedure described in the Notification of Ministry of Industry No.6, B.E. 2540 (1997) was used to investigate the concentrations of heavy metals. The results showed that concentrations of all regulated heavy metals were within the regulatory limits.

Collivignalli and Sorlini (2002) showed the results of the leachate from MSWIFA concrete products, which were also confirmed with the standard for good environment. The MSWIFA aggregate was used in concrete mixture by stabilizing with cement. Therefore, the heavy metals were hardly leached from the cement products.

Derie (1996) informed the result according to the TCLP test for stabilized fly ash from municipal incinerators that the leachate from stabilized fly ash did not exhibit a character of toxicity; only too much Cr (VI) is liberated.

For this study, The MSWIFA cement mortars are investigated for the presence of heavy metals contained in the leachate according to the leachate extraction procedure described in the Notification of Ministry of Industry No.6, B.E. 2540 (1997). This test does not determine the total element content of the samples, but indicates the leaching potential of the elements.

CHAPTER III

METHODOLOGY

3.1 Materials

3.1.1 Municipal Solid Waste Incinerator Fly Ash (MSWIFA)

The two types of MSWIFA, Non-spayed MSWIFA and Sprayed MSWIFA were collected from Phuket municipal solid waste incinerator. Non-spayed fly ash was collected directly from hopper after it was injected with lime powder and captured in bag filter. Meanwhile, Sprayed fly ash was collected directly from ash pit; it was sprayed by water to prevent flying away. Each type of fly ash was sampled approximately 100 kg during the normal plant operation in June 2005. The fly ashes were collected in triple plastic bags during transportation and investigation. The characteristics of these ashes will be investigated because spraying process might have interaction, between fly ash and water, which can cause some characteristics changing.

3.1.2 Portland cement

The Elephant brand ASTM Type I Portland cement was used throughout the study, according to ASTM C150. This Portland cement was manufactured by Siam Cement Public Company Limited, Thailand.

3.1.3 Natural Fine Aggregate

The natural fine aggregate is sand which met the requirement of ASTM C33. River sand was used for producing cement mortar specimens.

3.1.4 Water

Normal tap water was used as mixing water for all mixes.

3.2 Procedures

3.2.1 Characterization of MSWIFA (Both non-sprayed and sprayed fly ash)

3.2.1.1 Particle Size Distribution (PSD)

The Particle Size Analyzer (PSA) is the equipment which is used to define the particle size distribution (PSD) of fine materials. Both sprayed and non-sprayed MSWIFA were defined the particle size in order to compare between each other. The Malvern Particle Size Analyzer model Mastersizer 2000 equipped with the Scirocco was used in the study. The MSWIFA were directly measured with using liquid as a medium. The achieved results are the average value of three measurements.

Particle size of material has a significant effect on the rate of hydration reaction with cement and the properties of concrete. Finer particles have more specific surface and thus cause good interaction of cement product (Neville, 2003).

Procedure	Process
Material Sampling	- Non-sprayed and Sprayed fly ash was collected from Phuket MSW incinerator
Characterization of MSWIFA	- Particle size distribution (PSD) (by PSA) - Moisture content & LOI - Bulk chemical compositions (by XRF) - Mineralogical compositions (by XRD) - Total heavy metals (by EPA Method 3052 & ICP) - Heavy metal leaching (Notification of MOI No.6 B.E.2540)
Solidification/Stabilization of MSWIFA and Recycled Aggregate Production	- Pre-treatment: Washing to eliminate chloride - To quantify the appropriate ratio of MSWIFA and Portland cement to make recycled aggregate - Crushing samples - To characterize the properties of recycled aggregate and to compare with natural aggregate (ASTM C33)
Cement Mortars Production	- Preparation of test specimens (TIS 15 Part 17-2516 (1973)) - Casting and Testing of specimens: Compressive Strength (TIS 15 Part 12-2532 (1989))
Characterization of Leachate	- To quantify the heavy metals leached from mortar (Monolithic and Crushed sample) (Notification of MOI No.6 B.E.2540)
Discussions and Conclusions	- To discuss in terms of Utilization and Economical concern

Figure 3.1 Flow Diagram of Methodology

3.2.1.2 Moisture Content and Loss on Ignition (LOI)

The technique that is used to determine moisture content is described in ASTM C311. Approximately 50 grams of sample was dried in a ceramic cup in the oven at temperature of 105 – 110 °C. After that, it was cooled at room temperature in the dessicator to prevent moisture absorption from the atmosphere. The weight loss is assumed to be the absorbed water.

Loss on ignition (LOI) is typically defined the carbon content in the sample. According to ASTM C 311 and ASTM C 114, LOI can be determined by igniting 1 gram of MSWIFA, the residue from moisture content determination, in the porcelain crucible to constant weight in a muffle furnace at 750 ± 50 °C. The weight loss after ignited was assumed to be carbon content in MSWIFA. High carbon contents can cause air-entrainment problems and can adversely affect the performance of fly ash concrete. So that, LOI can be used as an indicator of the degree of burnout in fly ash as well as defining the combustion efficiency.

3.2.1.3 Bulk Chemical compositions

X-ray fluorescence (XRF) spectroscopy is a mean of the identification of elements presenting in the materials. Two major methods are wavelength dispersive spectroscopy (WDS) and energy dispersive spectroscopy (EDS). In the WDS method, X-rays is used to excite the transition of electrons of samples going to the excited state. While excited electrons return to the ground state, they will emit the fluorescent radiation. This fluorescent radiation from the sample is used as a source of the incident beam instead of X-rays or other particle waves like in XRD. The known analyzer crystal is used as a target for the incident beam. Then the scattered beams from the analyzer are detected. The EDS, however, detects and analyzes the energy distribution on the produced fluorescence radiation from the samples directly. Most detectors are solid-state detectors such as a Si(Li) or Ge(Li).

In this study, a wave length dispersive PANalytical X-ray Fluorescence Spectrometer model Axios System, from now on XRF, was used to analyze the oxide compositions of the samples. Firstly, the sample was ground to homogenously fine powder because the X-rays can only penetrate up to a few millimeters from surface of a sample. Next, 1.5 grams of the binding material was added to the approximate 5 grams of ground sample before being pressed into a pellet for convenient handling and measurement. The pressed samples were then put in sample solid cups on a feeder tray, of the instrument for analysis.

3.2.1.4 Mineralogical Compositions

The powder X-ray diffraction (XRD) spectrometer, Bruker model D8 Advance, was used to identify mineralogical compositions of MSWIFA in terms of crystalline phases. XRD patterns were achieved with a computer-controlled diffractometer equipped with a copper X-ray tube and a scintillation detector. A graphite monochrometor was used to produce diffracted lines according to a single X-ray wavelength with low background. Samples were prepared by dehydrating in an oven and sieving by No.200 of sieve mesh. the instrument's conditions were operated and set at 40 kV accelerating voltage, 40 mA current, 0.02 step per second, and 10° to 65° 2 theta (θ) scanning range. The phase patterns measured from XRD were matched against a powder diffraction file database (PDF) developed by the International Center for Diffraction Data (ICDD) that contains patterns for a large number of compounds.

3.2.1.5 Total heavy metals

Using microwave digestion method according to EPA Method 3052, Microwave Assisted Acid Digestion of Siliceous and Organically Based Matrices was to investigate the total heavy metals, eight elements in regular standards, in MSWIFA. This method is applicable to the microwave assisted acid digestion of siliceous matrices, and organic matrices and other complex matrices. The aim of this method is total decomposition and with judicious choice of acid combinations. The summary of

this method: a representative sample of 0.5 gram is digested in 9 mL of concentrated nitric acid and 3 mL hydrofluoric acid for 15 minutes using microwave heating with a suitable laboratory microwave system. The temperature profile is specified to permit specific reactions and incorporates reaching 180 ± 5 °C in approximately less than 5.5 minutes and remaining at 180 ± 5 °C for 9.5 minutes for completion of specific reactions.

3.2.1.6 Heavy metals in leachate

MSWIFA was examined the leachate contained the heavy metals according to the Notification of Ministry of Industry No.6, B.E. 2540 (1997) as in Table 3.1. The leachates were conducted and analyzed the heavy metals according to the method provided in the Notification of Ministry of Industry No.2, B.E. 2539 (1996).

Table 3.1 Limitation of Heavy Metals Concentrations in Leachate by Leaching Test

Element	Silver (Ag)	Arsenic (As)	Barium (Ba)	Cadmium (Cd)	Chromium (Cr)	Mercury (Hg)	Lead (Pb)	Selenium (Se)
Regulatory limit* (mg/L)	5.0	5.0	100.0	1.0	5.0	0.2	5.0	1.0

Note: *Notification of Ministry of Industry No.6, 1997

3.2.2 Stabilization and Solidification of MSWIFA

3.2.2.1 Preliminary Treatment of MSWIFA:

Both types of MSWIFA would be washed by tap water in washing process

Washing Process

In this study, washing process was used to pre-treat the MSWIFA in order to reduce chloride and sulfate content. Chloride could cause expansion and reinforcing steel corrosion problem in concrete structure. Washing process would be made by mixing MSWIFA with water for 30 minutes, with liquid/solid ratio of 5 by weight. The pH would be measured. Settling was required for 24 hrs. Afterwards, washed water would be removed, caring loss of fine particles. Then, washed MSWIFA would be dried in stove at temperature 105°C for 24 hrs or until dried. Finally, the dried MSWIFA would be ground as powder by mortar.

Table 3.2 Steps of Washing Process

Step	Time	Comment	Note
Mixing with Water	30 mins.	Using lab mixer	pH measuring
Settling	24 hrs.		pH measuring
L/S Separating			Cl^-measuring
Drying	24 hrs.	At 105°C	
Grinding		Ground as powder	

3.2.2.2 Stabilization and Solidification (S/S)

Stabilization and Solidification process

The recycled aggregate would be made by mixing both types of MSWIFA with Portland cement by varying ratio of MSWIFA and Portland cement

following Table 3.2. Bulk solidified products were stabilized at room temperature for 10-15 days. After that, bulk specimens were crushed and ground to reduce the particle size into natural sand size. The process is aimed to reduce the interference on cement mortar mechanical quality. The product from this process was called “Recycled Aggregate”.

Table 3.3 Stabilization and Solidification Process; Mixed Proportions for Producing Recycled Aggregate

Reagent / Recycled Aggregate Types	Portland Cement	Water	Fly ash
SRA1	10	50	100(SFA)
SRA2	15	50	100(SFA)
SRA3	20	50	100(SFA)
FRA1	10	50	100(FA)
FRA2	15	50	100(FA)
FRA3	20	50	100(FA)

Note: *Reagents dosage is expressed as percent (%) with respect to fly ash.

3.2.3 Characterization of Aggregates (Testing of Sand and Recycled Aggregate)

After the Solidification/Stabilization process, the recycled aggregates were tested, in order to use in concrete mixture, according to ASTM C 33 and would be compared with natural fine aggregate or sand. The characteristics that were used for testing is below;

3.2.3.1 Sieve Analysis and Fineness Modulus

This method was used for dividing a sample of aggregate into fractions, each consisting of particles of the same size. The test sieves used for concrete aggregate have square openings and their properties are prescribed by ASTM E 11. According to ASTM C 136 the sieves were placed above the other in order of size with the largest sieve on the top. The material retained on each sieve after shaking represents the fraction of aggregate coarser than the sieve in below but finer than the sieve above. The sieves could be described by the size of the opening (in inches) for larger sizes, and by the number of opening per lineal inch for sieves smaller than about ¼ inch. The standard approach is to designate the sieve sizes by the nominal aperture size in millimeters or micrometers. The sieves size 3/8 inch and the number of 4, 8, 16, 30, 50, and 100 were used in the test.

3.2.3.2 Deleterious Substances: Organic Impurities in Fine Aggregate

Natural aggregate might be sufficiently strong and resistant to wear. However, it might not be satisfactory for concrete-making if it contains organic impurities which interfere with the chemical reactions of hydration. The organic matter found in aggregate usually consists of products of decay of vegetable matter and appears in the form of humus or organic loam. The test is done by the colorimetric test of ASTM C 40. The acids in the sample were neutralized by a 3 percent solution of NaOH. Then, the mixture is vigorously shaken to allow the intimate contact necessary for chemical reaction, and then left to stand for 24 hrs, when the organic content can be judged by the color of the solution: the greater the organic is, the darker the color is. If the observed color is darker than the standard yellow, the aggregate has a rather high organic content.

3.2.3.3 Soundness

This is the term used to describe the ability of aggregate to resist excessive changes in volume as a result of changes in physical conditions. Lack of soundness is thus distinct from expansion caused by the chemical reactions between the aggregate and the alkalis in cement. A sample of graded aggregate is alternatively subjected to immersion in a saturated solution of sodium or magnesium sulfate and drying in an oven. The formation of salt crystals in the pores of the aggregate tends to disrupt the particles. This method was done according to ASTM C 88.

3.2.3.4 Material Finer than 75 μm in Aggregate by Washing

The material which is fine could cause the reaction of cement. Due to the water required in the hydration. The more water is added in concrete proportion, the finer the material becomes. The test used the sieve number 200 by filtering water, with suspended solid and dust, from aggregate washing step. After that the material retained on sieve was injected by water into washed aggregate again. Let it dry before weight washed aggregate compare with the first weight of aggregate before washing (according to ASTM C 117).

3.2.4 Properties of Cement Mortars including Recycled Aggregate

Strength of Concrete

The mechanical strength of hardened cement is the property of the material that is perhaps most obviously required for structural use. The strength of mortar or concrete depends on the cohesion of the cement paste, on its adhesion to the aggregate particles, and to a certain extent on the strength of the aggregate itself. Strength tests are not made on a neat cement paste because of difficulties of molding and testing with a consequent large variability of test results. Cement-sand mortar and concrete of prescribed proportions and made with specified materials under strictly

controlled conditions, are used for the purpose of determining the strength of cement (Neville, 2003).

The most important property required for harden concrete is compressive strength. Due to other strengths of concrete such as tensile strength, flexural strength, and shearing strength, they are proportioned with the compressive strength. Therefore, if cement mortar or concrete have high compressive strength. Others will have high compressive strength too.

Strength of concrete and cement mortar comes from testing of concrete specimen following a standard. Strength of concrete from testing might have more fluctuation, though the concrete specimen is made from same ingredients and mixing method. Because of an arrangement of ingredients is not homogeneously. Therefore, many specimens are needed to use to be an average.

3.2.4.1 Preparation of test specimens

The test specimens were designed and prepared in the blending step, to control quality of each specimen, according to the standard of Thailand Industrial Standards Institute, TIS 15 Part 17-2516 (1973): Portland cement Part 17 Method of mechanical mixing of hydraulic cement mortars. The ratios between natural sand and recycled aggregate were designed following Table 3.3 for use as aggregate in cement mortar mixture.

3.2.4.2 Casting and Testing of Specimens:

The compressive strength would be tested according to the standard of Thailand Industrial Standards Institute, TIS 15 Part 12-2532 (1989): Portland cement Part 12 Test method for compressive strength of hydraulic cement mortars, Thailand Industrial Standards Institute, Ministry of Industry. The development of compressive strength would be analyzed by curing the test specimens in the following period of time: 1, 7, 14, 28, and 50 days. Triplicates of sample were cast and tested in the all of

compressive strength test so that the average was reported. After 24 hours, all of the specimens were demolded and cured in the moisture condition until the time of testing.

Table 3.4 Ratio of Recycled Aggregate and Natural Fine Aggregate (Sand) in Cement Mortars and Amount of Test Specimens

Group	[Cement : Aggregate : Water] [1 : 2.75 : 0.485] Recycled Aggregate : Sand Ratio	Comment	No. of Specimens	Note
1	0 : 100	Used as a control	1*3=3	It will include each curing time of strength test
2	10 : 90	Use SRA & FRA type 1-3	6*3=18	1, 7, 14, 28, 50 days
3	20 : 80	Use SRA & FRA type 1-3	6*3=18	
4	30 : 70	Use SRA & FRA type 1-3	6*3=18	
5	40 : 60	Use SRA & FRA type 1-3	6*3=18	
			Total=75	Total=375

Table 3.5 Quantity of Materials to be Mixed at One Time in the Batch of Mortar for Making Six and Nine Test Specimens

Material	Number of Specimens	
	6	9
Cement, g	500	740
Sand, g	1375	2035
Water, mL Portland (0.485)	242	359

3.2.5 Leachate Characteristics of Cement Mortar

The MSWIFA cement mortar products were investigated for the presence of heavy metals contained in the leachate, according to the leachate extraction procedure described in the Notification of Ministry of Industry No.6, B.E. 2540. This test did not determine the total element content of the samples, but it indicated the leaching potential of the elements. Samples were crushed to particle size smaller than 9.5 mm. A hundred grams of crushed sample were mixed with synthetic acid rain extraction fluid, a combination of 80% sulfuric acid solution and 20% nitric acid solution in a liquid-to-solid weight ratio of 20:1, until pH of leachant reaches 5. The sample was then agitated in a rotary extractor for a period of 18 hours at 30 rpm and 25ºC. After 18 hours of agitation, the samples were filtered through a 0.6-0.8 μm glass fiber filters.

The water samples from filtering were analyzed for heavy metals, according to the method provided in the Notification of Ministry of Industry No.2, B.E. 2539. The analyzed heavy metals are silver (Ag), arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), Mercury (Hg), lead (Pb), and selenium (Se) by

Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) model VISTA-MPX. Afterward, the results were compared against the limits in the regulation to ensure that procedures were out of harm's way to environment and human health.

Table 3.6 Limitation of Concentrations of Heavy Metals in Industrial Waste Water and Limitation of Concentrations Heavy Metals in Leachate

Element	Limitation of concentrations of heavy metals from industrial waste water (Notification of MOI No.2, 1996), mg/L	Limitation of concentrations of heavy metals in leachate (Notification of MOI No.6, 1997), mg/L
Ag	-	5.0
As	0.25	5.0
Ba	1.0	100.0
Cd	0.03	1.0
Cr	0.25	5.0
Hg	0.005	5.0
Pb	0.2	0.2
Se	0.02	1.0

3.2.6 Environmental and Economical Feasibility Study

The information from each process would be discussed in terms of the optimal conditions of Utilization, Environmental and Economical concerns for the appropriate application method of MSWIFA management.

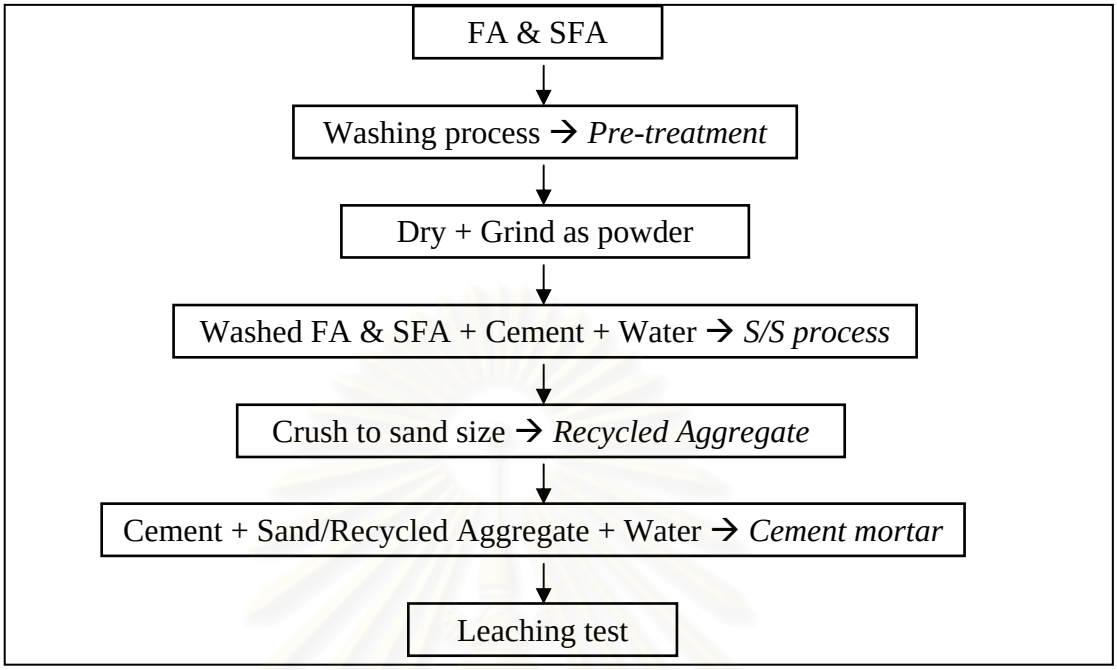

Figure 3.2 Flow Diagram of Recycled Aggregate Production and Cement Mortars Production

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Characteristics of MSWIFA

4.1.1 Particle Size Distribution

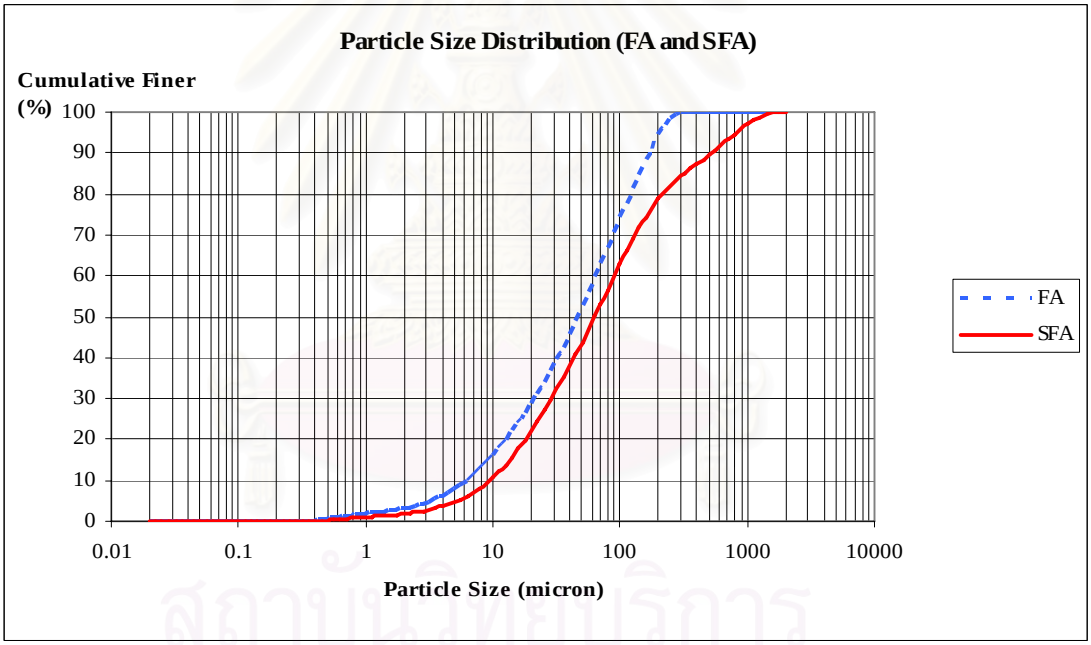

Figure 4.1 Particle Size Distribution (PSD) of Non-sprayed and Sprayed Fly Ash

Particle size distributions (PSD) of MSWIFA, both non-sprayed fly ash (FA) and sprayed fly ash (SFA) were characterized by the particle size analyzer (PSA) using laser scattering technique. Figure 4.1 shows that, in general, particle sizes of the sprayed fly ash (SFA) are bigger than those of the non-sprayed fly ash (FA). The graph reveals at the similar particle size, FA has higher cumulative percent finer than

the SFA. This means that FA has finer particles than SFA. Spraying water on MSWIFA to prevent flipping causes the MSWIFA to form agglomerates and became larger. The mean particle size ($d_{50\%}$) of FA is approximately 50 μm while that of SFA is 70 μm.

Particle size of MSWIFA affects its reaction with cement and water requirement in solidification and stabilization or S/S process and workability in concrete work. The size of MSWIFA particle depends on, among many things, incineration process, type of incinerator, MSW compositions in the feed, air pollution control device, and ash storage method. Moreover, FA is mainly dust due to the fact that it was directly collected from hopper at the bottom of bag filter house. Besides, the colors of MSWIFA are gray and dark gray for FA and SFA, respectively.

4.1.2 Moisture Content and Loss on Ignition (LOI)

Moisture content is free water which is determined by weight loss of MSWIFA in an oven at 105 ± 10 °C for 1 hour. The moisture content of MSWIFA depends on atmospheric condition and how the ash is stored. Normally, fly ash directly collected from a bag filter house has lower moisture than that collected from an ash pit. This is because the ash from pit was sprayed with some water to prevent dust or fine fugitive particles. Table 4.1 shows higher moisture content of SFA (4.04%) than FA (0.44%) because spraying water made MSWIFA wet and became agglomerated, thus increasing its weight for particle settling in ash pit as well. The washed FA and washed SFA have lower moisture content, 0.35% and 1.02% respectively, as they were dried in the oven after the washing process.

The loss on ignition values are shown in Table 4.1. LOI is roughly the carbon content of fly ash which is indicative of combustion condition of an incinerator. The LOI results of ignited samples are 3.86% for FA and 5.09% for SFA while washed FA and washed SFA show higher LOI values of 4.92% and 5.14% respectively, than raw FA and SFA. Since the washing process caused some

compounds in the MSWIFA to become hydrated the water was released when the ash was ignited at high temperature (750°C). However, LOI values of MSWIFA and washed MSWIFA, 12.44% and 17.33% respectively, from Sancharoen's study, which came from the same incineration facility in Phuket, are higher than the values obtained in this study. It might be because the combustion condition of the incinerator at Phuket at the time of sampling was improved in order to almost completely destroying carbon content in MSW.

Table 4.1 Moisture Contents and Loss on Ignitions (LOI) of Fly Ash Samples

MSWIFA	FA	SFA	Washed FA	Washed SFA
Moisture Content (%)	0.44	4.04	0.35	1.02
LOI (%)	3.86	5.09	4.92	5.14

4.1.3 Bulk Chemical compositions

The bulk chemical compositions of raw MSWIFA (i.e. FA and SFA) and washed MSWIFA (i.e. washed FA and washed SFA) were analyzed by X-ray fluorescence spectrometry (XRF). Oxide forms of elements are reported, in terms of percent by weight. The results reveal some significant differences between raw and washed materials. Chemical compositions of the raw MSWIFA are similar to results from previous researchers, Inthasaro (2002) and Sancharoen (2003) who studied Phuket MSWIFA.

The results from X-ray fluorescence spectrometry are shown in Table 4.2. Calcium oxide (CaO) and Chloride (Cl) are two major compositions in all of the samples which were measured at 43.57% and 40.53% for CaO and 22.17% and 23.40% for Cl, for FA and SFA respectively. These two elements are generally present in high amount because of the air pollution control process (APC) where lime

is injected to neutralize acid flue gases such as HCl (hydrogen chloride) and SO_2 (sulfur dioxide). Their products are $CaCl_2$ (calcium chloride) and $CaSO_4$ (calcium sulfate) salts. Furthermore, excess lime is normally used to achieve an alkaline condition required to transform heavy metals into insoluble forms. As for chlorides, MSW contains plastics, newspapers, and petrochemical products that are sources of chloride. For these reasons, CaO and Cl, in MSWIFA (FA and SFA) are present in high quantities. Other major compositions are Na_2O, K_2O, SO_3, and SiO_2. Heavy metals were surely detected but shown in trace quantities; for instance, Co, Cu, Fe, Mo, Mn, Pb, Sb, Sn, Sr, Ti, and Zn.

Table 4.2 Chemical Compositions of Raw MSWIFAs and Washed MSWIFAs

Compound	FA	SFA	Washed FA	Washed SFA
Na_2O	6.64	6.25	1.61	1.07
MgO	1.40	1.57	2.77	2.52
Al_2O_3	1.39	1.37	2.81	2.48
SiO_2	3.40	2.94	6.83	4.60
P_2O_5	1.21	1.03	2.45	1.69
SO_3	6.64	7.24	8.58	9.91
K_2O	6.45	7.55	1.70	1.21
CaO	43.57	40.53	56.81	58.52
TiO_2	0.69	0.58	1.38	0.97
MnO	0.05	0.02	0.09	0.05
Fe_2O_3	0.99	0.60	1.59	1.16
Co_3O_4	0.02	0.02	0.03	0.03
CuO	0.09	0.09	0.14	0.14
ZnO	0.88	1.14	1.42	1.86
Rb_2O	0.04	0.05	0.00	0.00
SrO	0.06	0.05	0.08	0.05
Y_2O_3	0.00	0.00	0.00	0.00
ZrO_2	0.02	0.00	0.02	0.02
MoO_3	0.04	0.04	0.04	0.04
CdO	0.00	0.00	0.02	0.02
SnO_2	0.08	0.07	0.12	0.13
Sb_2O_3	0.05	0.00	0.10	0.11
PbO	0.16	0.23	0.19	0.31
Cl	22.17	23.40	6.25	7.88
Br	0.07	0.10	0.03	0.06
I	0.03	0.03	0.03	0.03
LOI	3.86	5.09	4.92	5.14
Total	**100.00**	**100.00**	**100.00**	**100.00**

Chloride can cause corrosion to reinforced steels in concrete construction. Since high amount of chloride in MSWIFA samples (22.17% and 23.40% for FA and SFA) may cause problems in concrete applications, washing process was then applied to remove chloride before further applications.

The chemical compositions of washed FA and washed SFA were monitored to verify the change in chemical compositions. The results show that the amount of chloride was reduced after the washing process, from 22.17% (FA) to 6.25% (washed FA) and 23.40% (SFA) to 7.88% (washed SFA). Another observation is that the quantities of K_2O and Na_2O are present in lower amounts compared with those of raw FA and SFA. The washing process was able to remove the soluble compounds particularly chloride compounds, KCl and NaCl from MSWIFA. These results are consistent with X-ray diffraction results in Section 4.1.4. Moreover, the reduction of soluble compounds causes the increasing of amount of the insoluble fractions.

4.1.4 Mineralogical Compositions

The crystalline phases of MSWIFA and washed MSWIFA which were analyzed by X-ray powder diffraction (XRD) spectrometer are shown in Figures 4.2 to 4.5. XRD spectra of raw MSWIFA, FA and SFA are provided in Figures 4.2 and 4.3. The dominant components in crystalline phases detected are KCl (sylvite) and NaCl (halite). Moreover, $CaCO_3$ (calcite), and $CaSO_4$ (anhydrite), $Ca(OH)_2$ (portlandite), CaClOH (calcium chloride hydroxide), and SiO_2 (quartz) were also detected. Other phases were hard to detect as the great complication and numerous overlapping peaks were involved with peak matching the peaks.

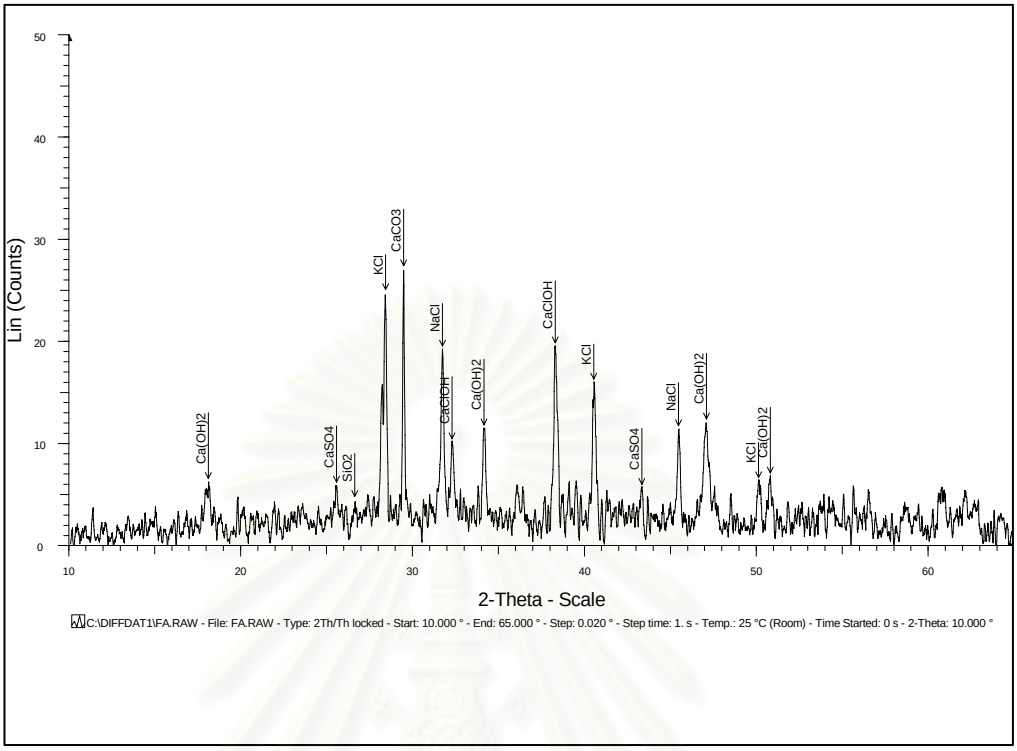

Figure 4.2 XRD Spectrum of Non-sprayed MSWIFA

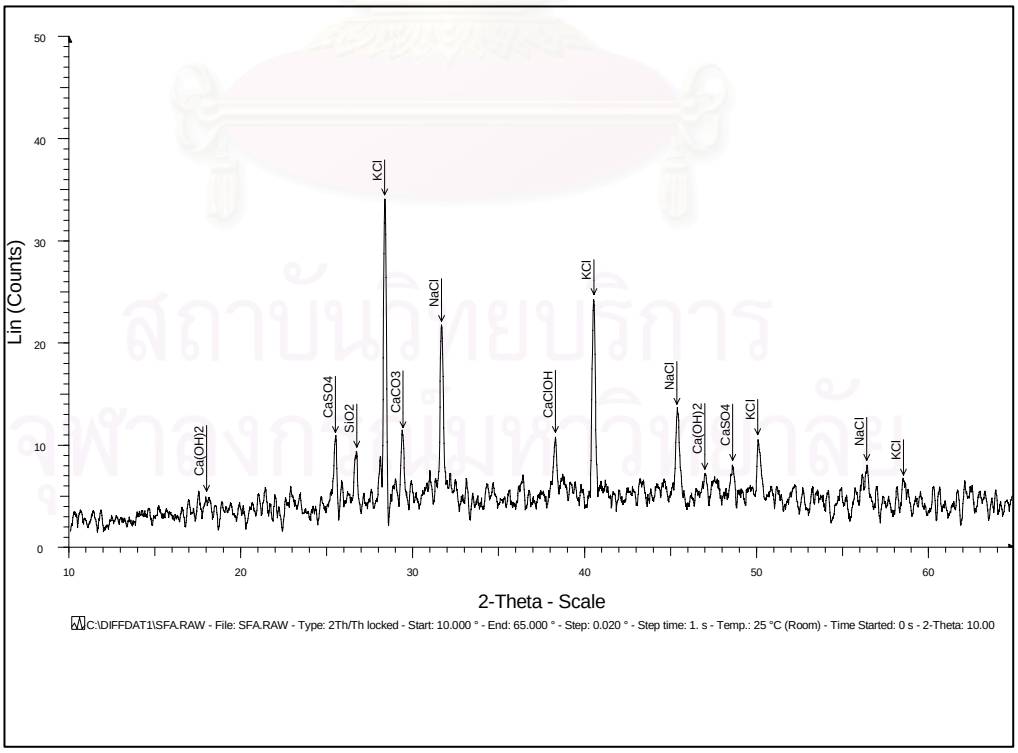

Figure 4.3 XRD Spectrum of Sprayed MSWIFA

Figures 4.4 and 4.5 show the XRD spectra of washed FA and washed SFA. KCl and NaCl, major compounds found in FA and SFA, are still present in washed FA and washed SFA, though at very low intensities. This is due to the fact that chloride compounds became soluble and were subsequently removed during the washing process. $Ca(OH)_2$ (portlandite), $CaCO_3$ (calcite), $CaSO_4$ (anhydrite), and SiO_2 (quartz) were also detected at the intensity as same as in FA and SFA.

These XRD spectra are in agreement with the bulk chemical compositions that were detected by the XRF. As the major compositions from the XRF results, Ca, Cl, Na, K, and SO_3 are consistent with the XRD spectra. After the washing process, chloride salts were removed with the wash water, so XRD spectrum shows their low intensities. It is reliable comparing with result from XRF in section 4.1.3.

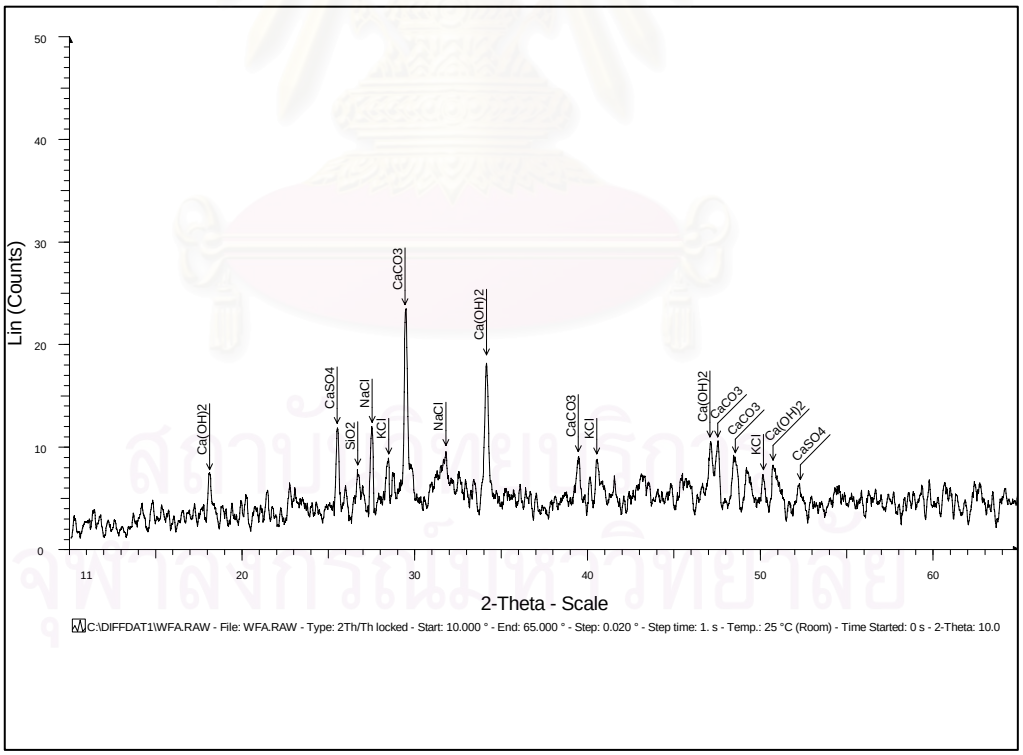

Figure 4.4 XRD Spectrum of Washed Non-sprayed MSWIFA

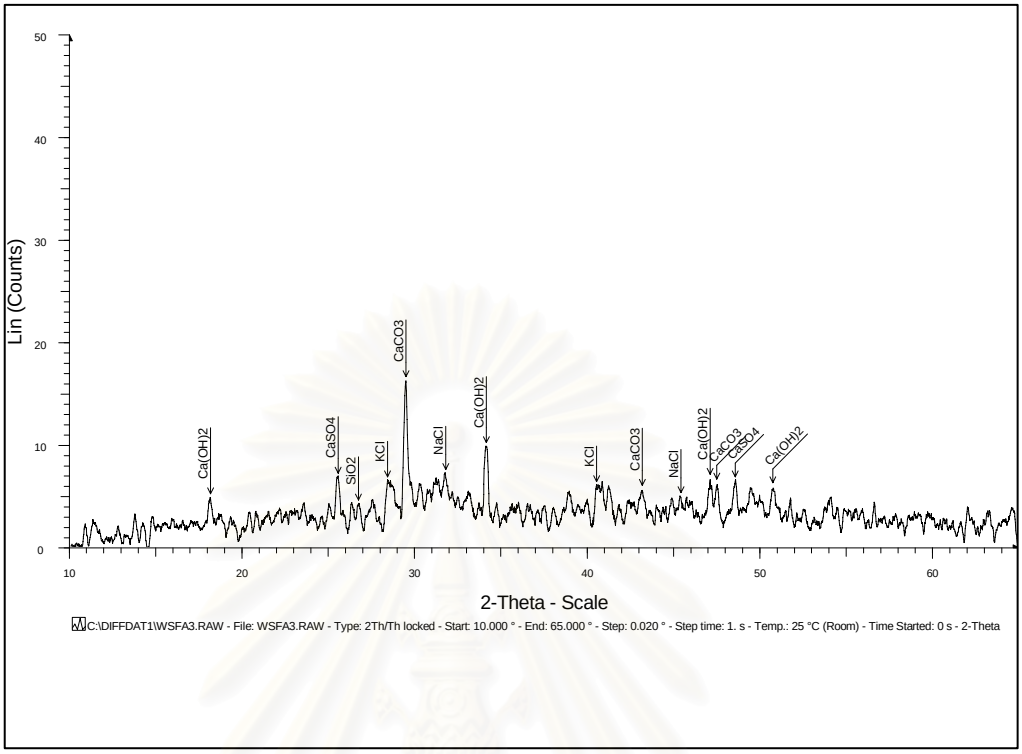

Figure 4.5 XRD Spectrum of Washed Sprayed MSWIFA

The chemical compositions of FA and SFA are somewhat different according to the results from the XRF and the XRD. Water spraying to MSWIFA did not have significant effect on its properties and chemical compositions.

4.1.5 Total Heavy Metals

The total heavy metals in MSWIFA determined by microwave digestion and ICP are revealed in Figure 4.6. As compared with results from leaching test of raw MSWIFA in section 4.1.6, concentrations of eight heavy metals are shown by unit of mg/kg of fly ash. The concentration of lead (Pb) was the highest of all the eight elements. Although other heavy metals were present in lower concentrations than lead (Pb) but they may pose a threat of heavy metal leaching to the environment. For selenium (Se), the concentration was very low. That might be because only 0.5 gram of sample was weighed and used in microwave digestion step. It can be seen

that the amounts of total heavy metals in the FA and SFA are similar. Evidently, water spraying on MSWIFA did not have any clear effects on the amount of total heavy metals contained in MSWIFA.

As compared with the results from X-ray fluorescence spectrometry (XRF), it is apparent that amount of lead (Pb) detected are the highest of all eight investigated heavy metals in fly ash samples. For other heavy metals, it should be noted that their concentrations are in very low quantities that they cannot be shown in Table 4.2.

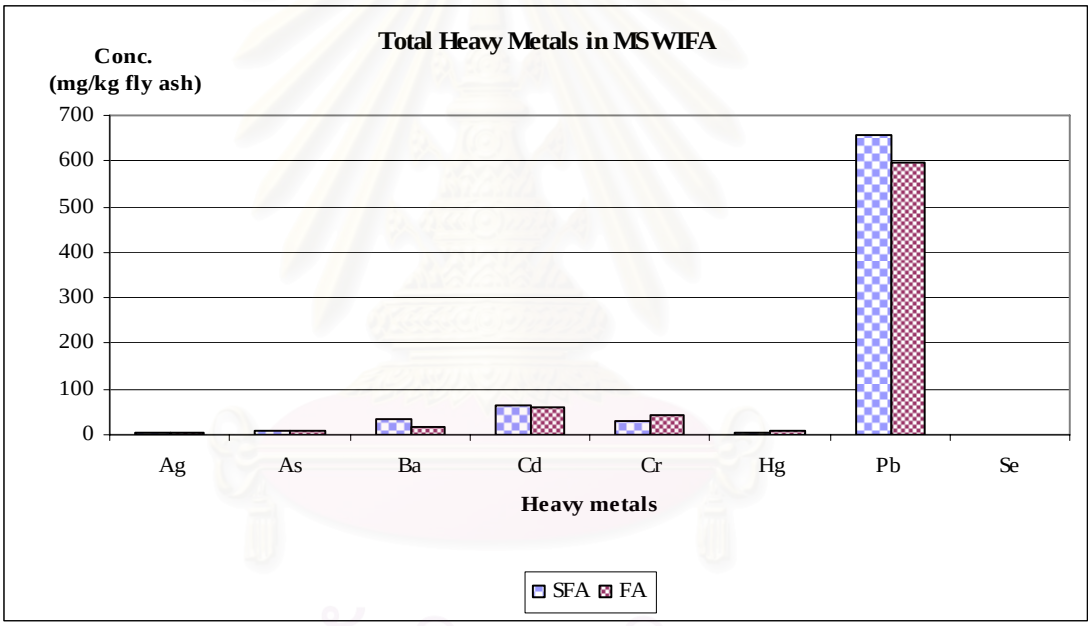

Figure 4.6 Total Heavy Metals in MSWIFA, Both FA and SFA

4.1.6 Heavy Metals in Leachate

The leaching test is done for testing the potential of heavy metals to leach out of the disposed waste. The heavy metal laden leachate from landfill receiving MSWIFA in this case, could pose a great risk to groundwater in the event of

liner leakage. Thus, groundwater which is an important source of raw water for local citizens is in jeopardy.

The heavy metals in leachate were then investigated by the leaching test of both FA and SFA. Figure 4.7 reveals concentrations of lead (Pb) that are higher than other measured heavy metals and also exceeded the regulatory limit of 5 mg/L. Besides, the concentrations of selenium (Se) of both samples were found to exceed the regulatory limit while the concentrations of mercury (Hg) almost exceeded the standard. High concentrations of lead (Pb) in the fly ash came from the municipal solid waste compositions since municipal or household solid waste usually contains plastics, batteries, or electronic wastes.

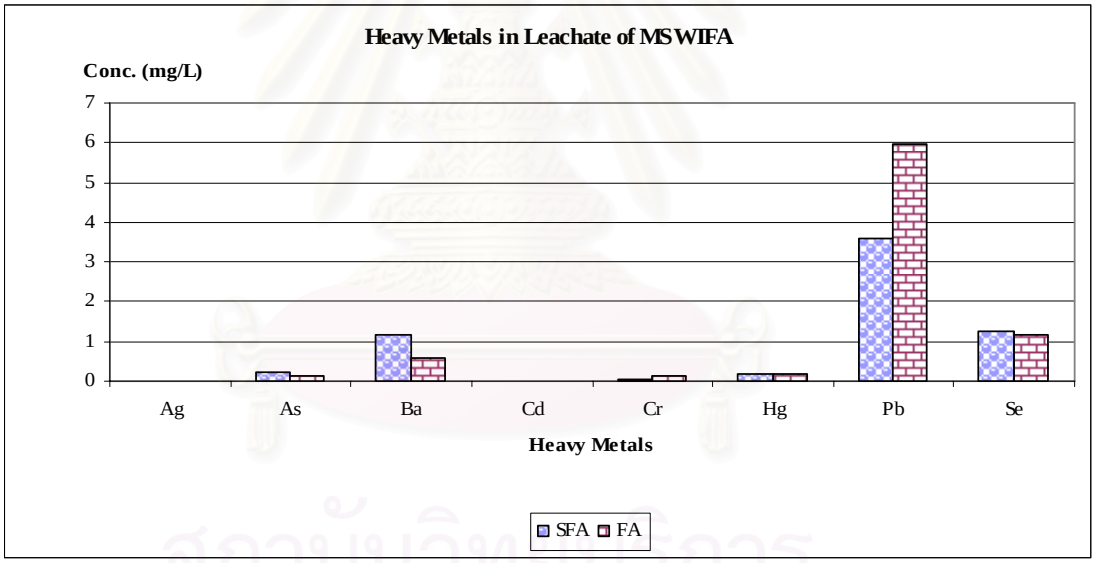

Figure 4.7 Heavy metals in Leachate of MSWIFA, Both FA and SFA

The result of leaching test could be used to compare against the concentration limits to legally characterize if MSWIFA is a hazardous waste, according the Notification No.6 of the Ministry of Industry B.E. 2540 (1997). If it is, it will need proper management, not only directly dumping into a sanitary landfill.

Table 4.3 Limitation and Concentrations of Heavy Metals in Leachate MSWIFA, FA and SFA

Element	Regulatory Limit* (mg/L)	Average Concentration (mg/L)	
		FA	SFA
Silver (Ag)	5.0	<0.010	<0.010
Arsenic (As)	5.0	0.140	0.200
Barium (Ba)	100.0	0.600	1.170
Cadmium (Cd)	1.0	<0.005	<0.005
Chromium (Cr)	5.0	0.130	0.040
Mercury (Hg)	0.2	0.190	0.190
Lead (Pb)	5.0	5.990	3.580
Selenium (Se)	1.0	1.180	1.240

Note: *Notification of Ministry of Industry No.6, B.E. 2540 (1997)

4.2 Preliminary Treatment of MSWIFA

4.2.1 Chlorides from Washing Process

Due to the fact that high amount of chloride can cause the corrosion of the reinforce concrete, the washing process was performed to reduce chloride from raw MSWIFA prior to utilization. Both wastewaters from washing FA and SFA were analyzed for the amount of chlorides. The results show high amount of chlorides dissolved in washed water as in Figure 4.8. In addition, the result of XRF also shows that chlorides are a major component in raw MSWIFA. The high amount of chloride may be due to the high amount of salts in MSWIFA, such as $CaCl_2$ and $MgCl_2$. The main source of chloride came from the petrochemical product i.e. plastic ware.

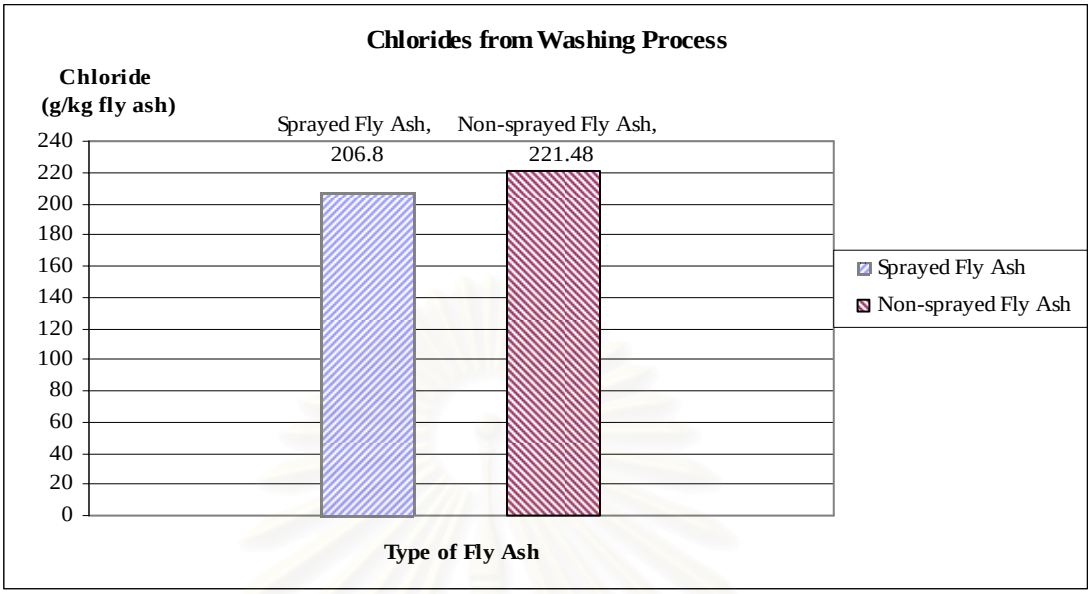

Figure 4.8 Chlorides from washing process, Both FA and SFA

4.2.2 pH of Wash Water

pH of the wash water was determined by a calibrated pH meter. It was noticed that the pHs of FA and SFA in the water after agitation by a mixer for 30 minutes were 11.83 and 11.88, respectively while the pHs after settling for 24 hours were 11.82 for the both of them. The fact that these four pH values were very close could imply that there was no reaction during settling period. Only chlorides and soluble compounds were dissolved into the water as in discussed section 4.2.1 and 4.2.3.

Generally, high pH value of fly ash is produced in an air pollution control (APC) device where lime (CaO) is used to neutralize acid flue gas. This is to reduce acid gas emissions and produce $CaCl_2$ and $CaSO_4$ powders in the process. These alkaline products and other alkaline materials, such as oxides and carbonates of calcium, sodium, and potassium give high pH.

By the way, the pH value of solution can be used as an indicator to estimate the ability of stabilized heavy metals. Because, most of trace elements such as heavy metals can be in the insoluble form as hydroxide compounds at high pH value. From the air pollution control process, the flue gas was neutralized by excess lime. After that, MSWIFA was washed by mixing with water. Therefore, the wash water with high pH value could be verified insoluble form of heavy metals which could be applied for further applications.

4.2.3 Heavy Metals in Wash Water

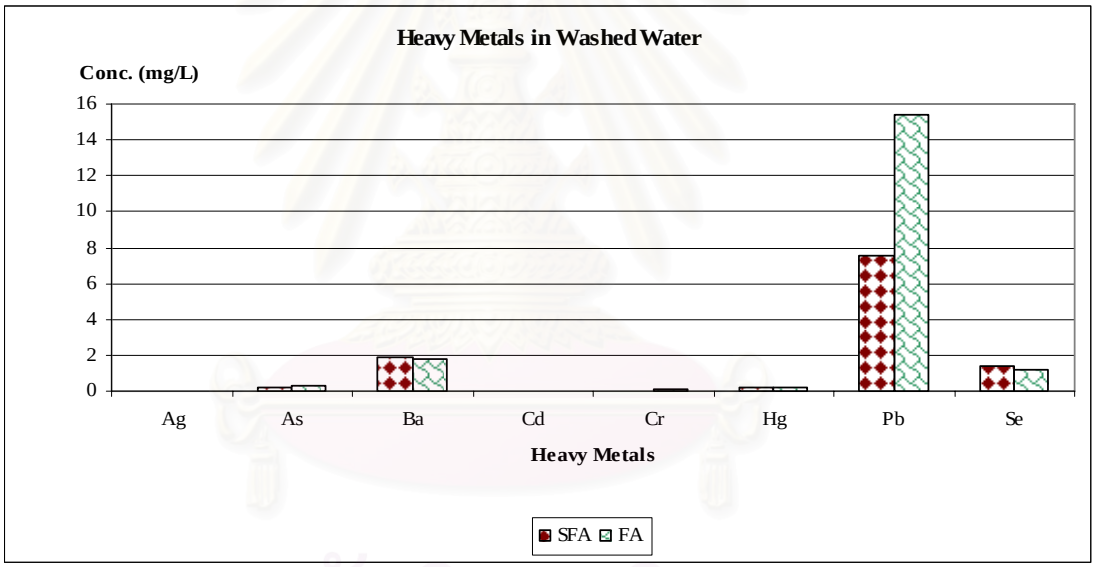

Figure 4.9 Heavy Metals in Wash Water of MSWIFA, Both FA and SFA

The heavy metals in waste water from washing process of both FA and SFA were investigated to address concerns regarding possible environmental impacts. The Notification of MOI No.2 B.E. 2539 (1996) set the concentration limits of waste water from industry as shown in Table 3.6. The concentrations of lead (Pb), selenium (Se), and barium (Ba) exceeded the limits as shown in Figure 4.9 while the concentrations of mercury (Hg) were close to the limit as well. All of heavy metal concentrations were in line with the amount of heavy metals in raw MSWIFA and

concentrations of heavy metals in the leachate of MSWIFA in sections 4.1.5 and 4.1.6. Consequently, if MSWIFA is to be pretreated before utilization, especially washing process, one should be aware of heavy metal concentrations exceeding regulatory limits in waste water.

4.2.4 Leaching Test of Washed MSWIFA

Table 4.4 Heavy Metals in Leachate of Washed MSWIFA; both Washed FA and Washed SFA

Element	Regulatory Limit* (mg/L)	Concentration of Heavy Metals (mg/L)	
		Washed FA	Washed SFA
Silver (Ag)	5.0	<0.010	<0.010
Arsenic (As)	5.0	<0.100	<0.100
Barium (Ba)	100.0	1.010	0.960
Cadmium (Cd)	1.0	<0.005	<0.005
Chromium (Cr)	5.0	0.440	0.360
Mercury (Hg)	0.2	<0.010	<0.010
Lead (Pb)	5.0	6.770	5.510
Selenium (Se)	1.0	2.430	2.300

Note: *Notification of Ministry of Industry No.6, B.E. 2540 (1997)

Table 4.4 reveals the concentrations of heavy metals in leachates of washed FA and washed SFA by leaching test method. Mostly heavy metals had their concentrations within the regulatory limit excluding lead (Pb), selenium (Se), and barium (Ba) exceeded the limit. It is noticed that the concentrations of heavy metals in leachate of washed FA and washed SFA are slightly higher than those in leachates of raw FA and SFA. One possible explanation for this is that some soluble compounds, such as chloride salts, dissolved well in the water through the washing process, thus

leaving mainly less soluble elements. That is why the concentrations of heavy metals of washed MSWIFA seemed higher than that of raw MSWIFA. Actually, the partial heavy metals are dissolved in washed water. This caused tendency of concentrations of heavy metals in leachate of washed MSWIFA is lower than MSWIFA.

4.3 Testing of Aggregates

4.3.1 Sieve Analysis and Fineness Modulus

The gradations of recycled aggregates (RA) depended on crushing step carried out after the stabilization and solidification process. Desired particle size ranges were proven difficult via manual crushing of samples due to the fact that the solidified fly ashes were fragile. Figures 4.10 and 4.11 show the gradation of ASTM C136-96 recommended values for fineness modulus (F.M.) of natural sand and F.M. of recycled aggregates. It could be explained that all types of recycled aggregate, FRA and SRA series, did not fit within the recommended size ranges (F.M. between 2.15 and 3.38) for most sieve sizes. Additionally, the particle sizes of all recycled aggregates were smaller than the recommended ranges. In real practice, natural sand or fine aggregates used in construction are usually not required to determine their gradation analysis since it is complicated and difficult to practice at a real site.

Fineness Modulus (F.M.) is a non-unit value used to indicate characteristic of natural sand, fine or coarse. Higher F.M. means sand is coarser than lower F.M. Due to the fact that natural sand has more fine materials, it need more water for mixing in order to the same workability. Therefore, the recommended value of F.M. should be in range of 2.15 to 3.38. Table 4.5 shows the F.M. values of all types of recycled aggregate. Those values are well below the recommended value, meaning that all of recycled aggregates are finer than natural sand and contained more very fine particles as well.

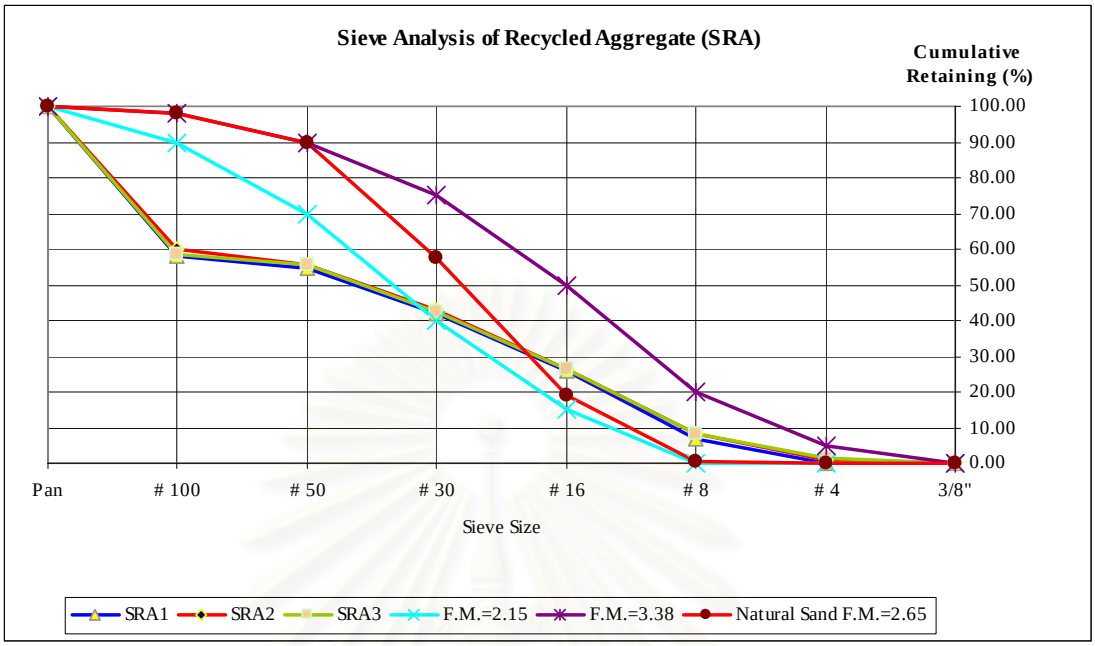

Figure 4.10 Gradation of Sieve Analysis of Sprayed Fly Ash Recycled Aggregate (SRA)

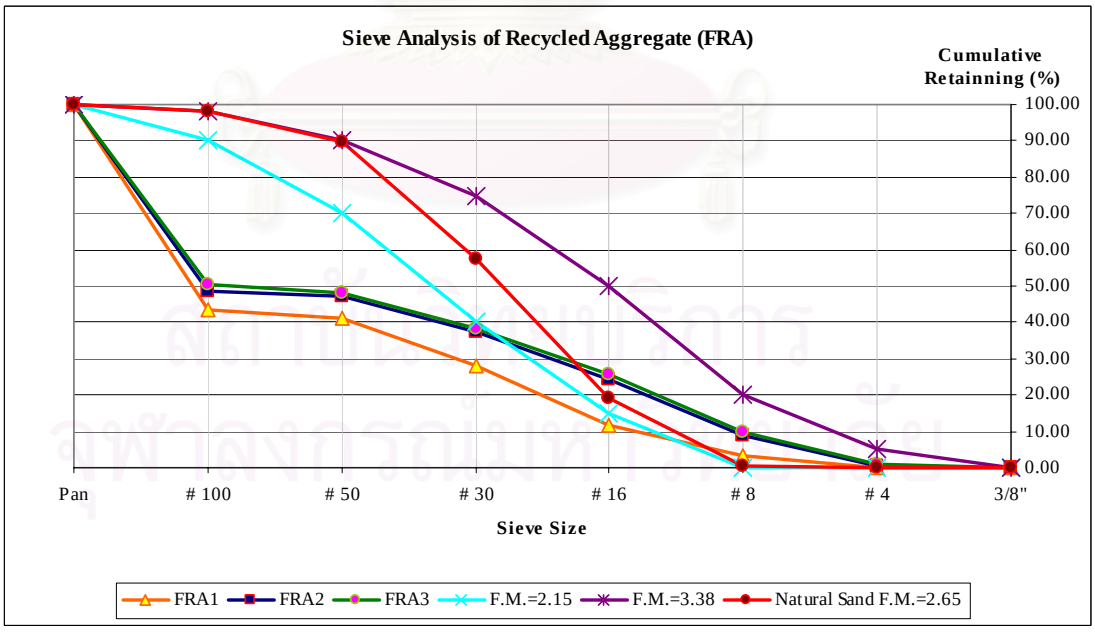

Figure 4.11 Gradation of Sieve Analysis of Non-sprayed Fly Ash Recycled Aggregate (FRA)

Table 4.5 Fineness Modulus of Recycled Aggregate

RA	F.M.	RA	F.M.
FRA1	1.27	SRA1	1.87
FRA2	1.67	SRA2	1.94
FRA3	1.74	SRA3	1.93
Natural sand*	2.25 – 3.38		

Note: *ASTM C136-96

4.3.2 Deleterious Substances: Organic Impurities in Fine Aggregate

Organic substances influence compressive strength of concrete because they could adversely affect hydration of cement. Nevertheless, most organic substances in municipal solid waste are destroyed at high temperature in combustion chamber of an incinerator, at approximately 900 °C. Then, it may result in less amount of organic substances is left in MSWIFA. Another possible reason is that the S/S process as recycled aggregate production probably encapsulates organic substances in the solid phase, thus preventing the organic substances to come in contact with hydrating cement ingredients.

In the experiment, colorimetric test was performed by submerging the recycled aggregates into sodium hydroxide (NaOH) solution. It was found that the solutions were muddy because fine materials in the recycled aggregates behaved like colloids in the solution. Therefore, this technique is inappropriate for analysis of organic impurities in fine aggregate.

4.3.3 Soundness

According to ASTM C88-05, soundness is needed for any aggregates which are used in construction. Since the aggregate is an inert material, it should not have any reactions with cement or other substances due to its function, which is only to contribute to the strength. The value which ASTM recommended for the loss of aggregate weight should not exceed 12 percent when sodium sulphate (Na_2SO_4) solution is used or 18 percent when magnesium sulphate ($MgSO_4$) solution is used.

The results from the experiment show only a little weight loss from the recycled aggregate. That means that the recycled aggregate should have good soundness. By the way, the soundness of recycled aggregate probably comes from cement hydration during stabilization and solidification process (S/S). Then the recycled aggregate would have an ability to resist the reaction of sodium sulphate (Na_2SO_4) solution or magnesium sulphate ($MgSO_4$) solution.

4.3.4 Materials Finer than 75 µm in Aggregate by Washing

ASTM C117-04 recommends that the amount of materials finer than 75 µm in fine aggregates used in general concrete construction should not exceed 5 percent. The fine particles (<75 µm, passing sieve # 200) would affect the property of concrete by reducing the bonding force between cement paste and aggregate. Besides, fine materials or dusts need more water for mixing and that can cause shrinkage of concrete and cracking when concrete solidifies. Consequently, the strength and durability of concrete will be reduced.

Table 4.6 Materials Finer than 75 μm (Dust) in Recycled Aggregate by Washing

RA Type	Weight before washing (g)	Weight after washing (g)	Dust (g)	% Dust
FRA1	615.24	554.74	60.50	9.83
FRA2	675.85	619.24	56.61	8.37
FRA3	598.21	546.84	51.37	8.58
SRA1	726.65	667.98	58.67	8.07
SRA2	624.93	579.16	45.77	7.32
SRA3	711.23	655.77	55.46	7.79

Table 4.6 reveals the amount of fine materials in each type of recycled aggregate. Apparently, the amount of dust or fine materials is more than the ASTM C117-04 recommended amount of not more than 5% in concrete structure. This is because it was difficult to achieve the required sizes by the manual crushing process during recycled aggregate production, as mentioned in the previous section (4.3.1). Comparison between FRA and SRA shows that the percent of fine materials or dust in FRA is slightly more than that of SRA.

The battery of aggregate tests was performed in this research in order to guarantee that the recycled aggregate would have no reaction with other substances. The vital role of aggregate is that it is an inert material that can withstand any reaction such as hydration of cement or chemical corrosion. In this case, all of recycled aggregate can be safely used in concrete with appropriate amount of replacement.

4.4 Properties of Cement Mortars Containing Recycled Aggregate

4.4.1 Compressive Strength

As shown in Tables 3.3 and 3.4, three types of recycled aggregate were used to replace natural sand in four designed proportions, at 10%, 20%, 30%, and 40% by weight for production of cement mortars. Then the compressive strengths were tested according to TIS 15 Part 12-2532 (1989) at the curing age of 1, 7, 14, 28 and 50 days. The development of compressive strengths are shown in Figures 4.12 to 4.15.

The compressive strength of cement mortar and concrete is important property to describe other properties as well. Because of other strengths are proportioned to compressive strength as mentioned in section 3.2.4. The compressive strength test of cement mortar was done by pressing force to standard specimens that were cured in designed curing age until specimens were cracked. A compressive strength test machine was used to determine compressive strength value. The highest pressing weight divided by area of standard specimen would be the compressive strength. This value is depended on mixing ratio, water quantity, age of specimen, and curing throughout shape and size of tested specimen.

Figures 4.12 to 4.15 show the effect of recycled aggregates on the compressive strength of cement mortars. It can be seen that the development of compressive strength, at 28 days of curing age, of cement mortars containing 10 percent sprayed fly ash recycled aggregate (M10 SRA) were the group with the highest strength values as shown in Figure 4.16. Furthermore, the cement mortars containing 20 percent sprayed fly ash recycled aggregate type 1 (M20 SRA1) achieved the highest compressive strength even when compared with control cement mortars (M00). However, for others, as the replacement percentage of recycled aggregate for sand became higher, the lower the compressive strengths were obtained as a result. Moreover, it can be found from Figures 4.12 to 4.15 that the compressive strength values of non-sprayed and sprayed fly ash recycled aggregate cement mortars

(MXX FRAX and MXX SRAX) seem to be equal at higher amounts of natural aggregate replacement. From the results, the differences of compressive strengths might have come from various sources. The major sources (affecting to compressive strength of cement mortars) are casting and compacting of specimens. Other effects are temperature, water requirement, quality of materials, non-homogeneous mixing, curing method, and human error.

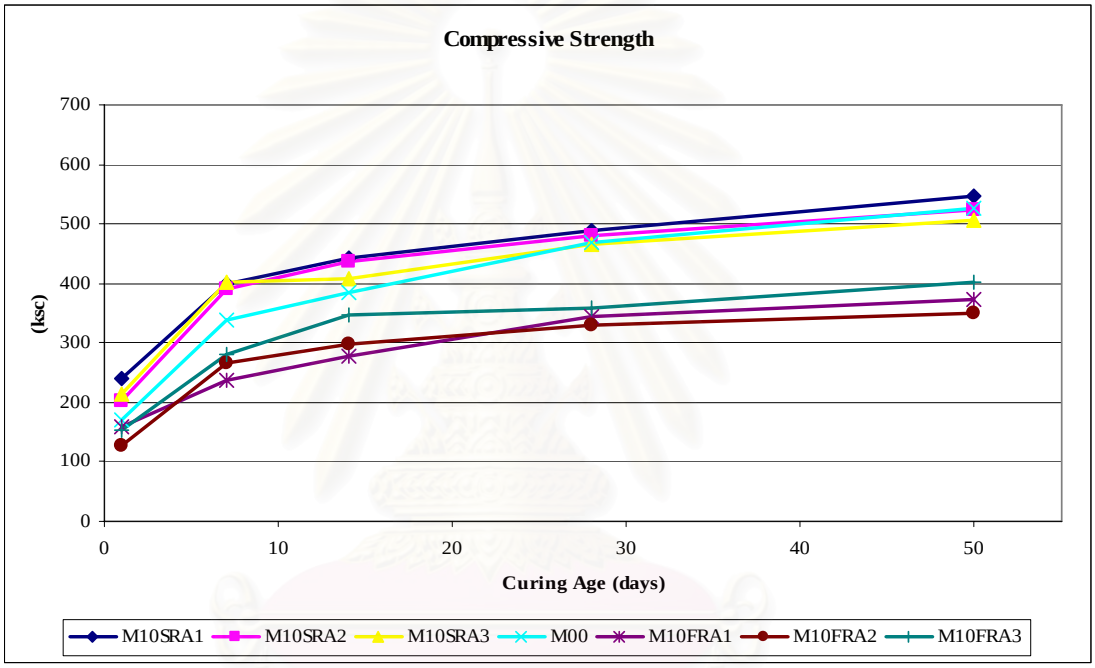

Figure 4.12 Compressive Strength Developments of Cement Mortars (M10)

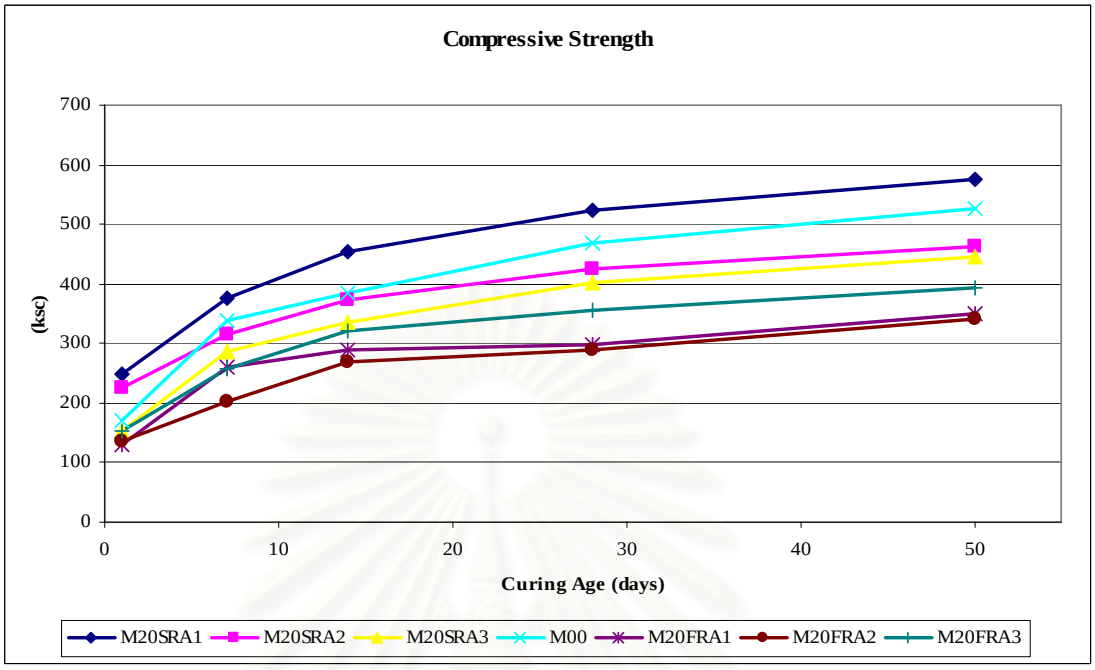

Figure 4.13 Compressive Strength Developments of Cement Mortars (M20)

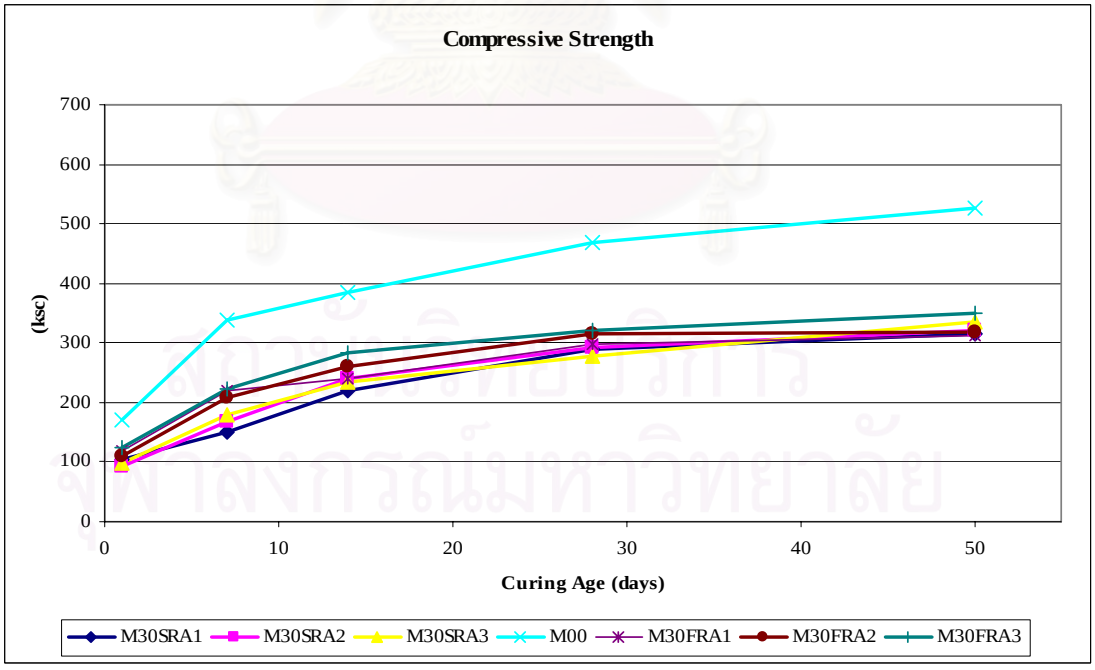

Figure 4.14 Compressive Strength Developments of Cement Mortars (M30)

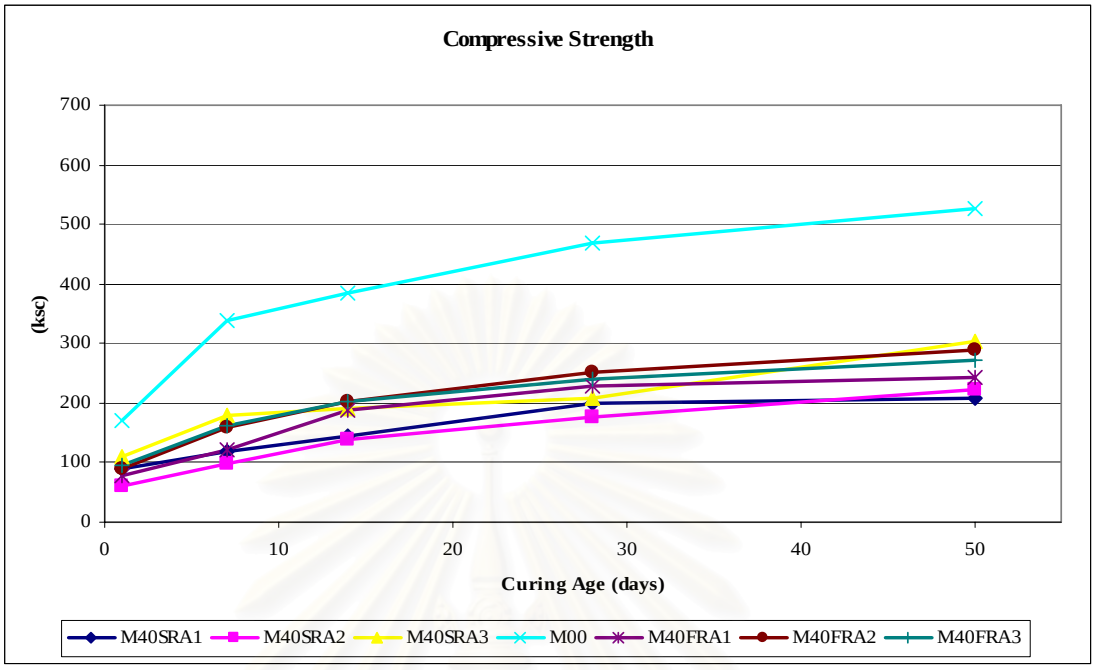

Figure 4.15 Compressive Strength Developments of Cement Mortars (M40)

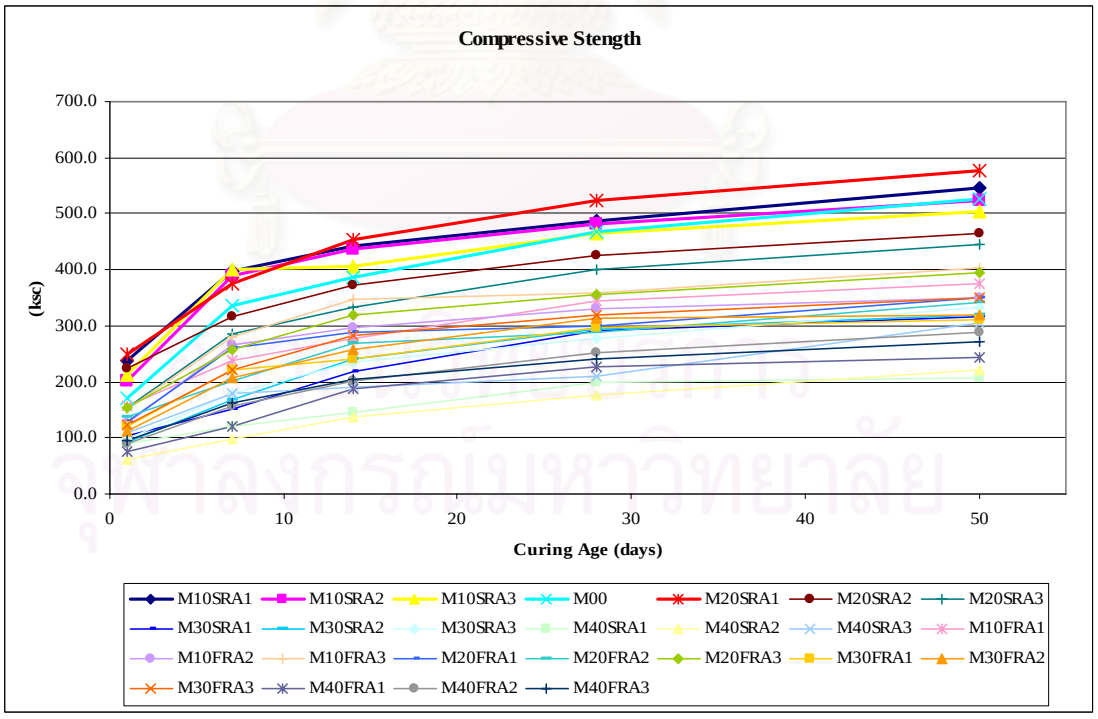

Figure 4.16 Compressive Strength Developments of All Cement Mortars

Finer particles in recycled aggregate can fill into spaces between cement and natural sand particles. Therefore, the low amount of replacement can make cement mortars achieving higher strength. In contrast, at higher aggregate replacement, the compressive strengths of cement mortars were reduced. Since, over quantities of fine particle cause specimens reducing weight resistance. Another reason may be due to water requirement or absorption capacity of recycled aggregate. Since the recycled aggregates had more fine particles, they needed more water in the mixing process of cement mortars for good workability. However, in the experiment, constant ratio of water was applied for all samples. This resulted in low workability, difficult casting and compacting in molds. Consequently, the compressive strengths were reduced depending on amount of sand replacement.

Figures 4.17 to 4.21 show the relative compressive strength of cement mortars containing recycled aggregate compared with the control cement mortar at the same curing age. The compressive strength of control cement mortar (M00) was normalized to 100% at all ages. Other samples were normalized to the control cement mortar at the same ages as well. The 28-day compressive strengths of M20SRA1 is 111.9% and the longest period of curing age (50 days), in this study the compressive strength is 109.5% compared with M00. These were the highest compressive strength value in the study. Moreover, group of M10 cement mortars that contained SRA1-3 achieved the highest compressive strength values at 28 days which are 104.2%, 102.4%, and 99.1%, respectively, and at 50 days which are 103.7%, 99.5%, and 96.0%, respectively compared with other specimens.

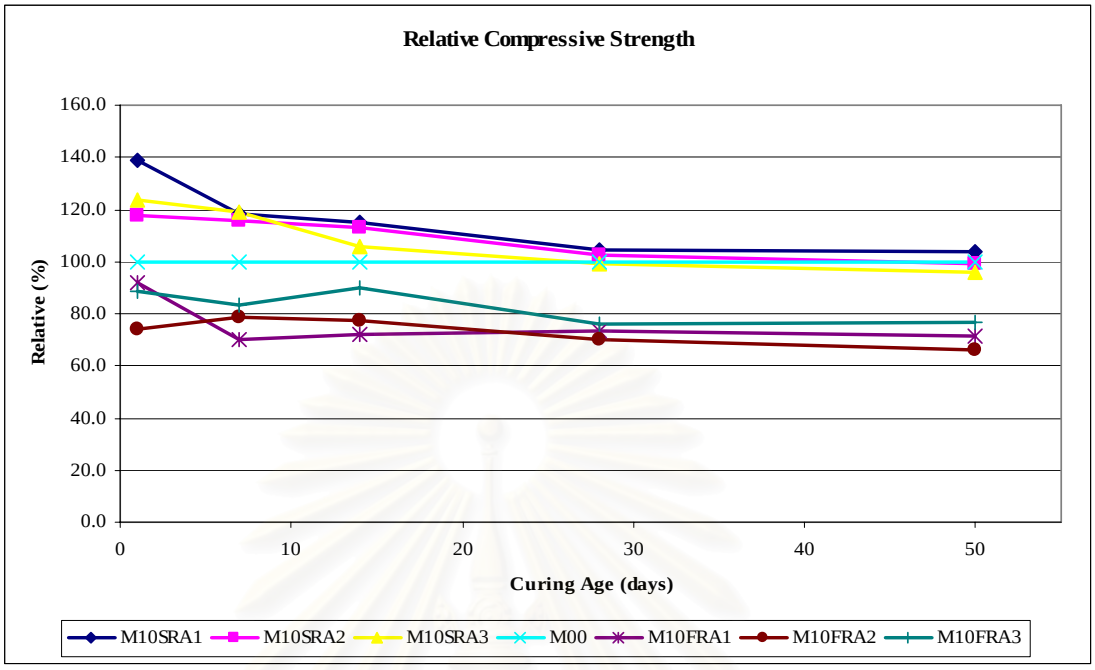

Figure 4.17 Relative Compressive Strength Developments of Cement Mortars (M10) Compared to that of Control Cement Mortar at the Same Age

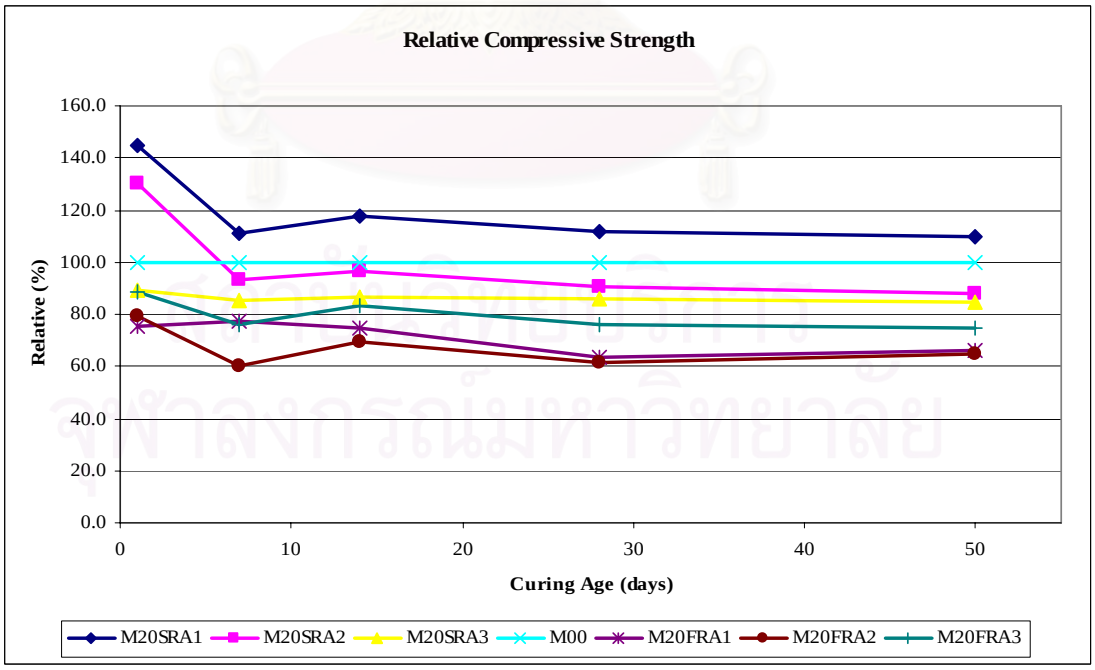

Figure 4.18 Relative Compressive Strength Developments of Cement Mortars (M20) Compared to that of Control Cement Mortar at the Same Age

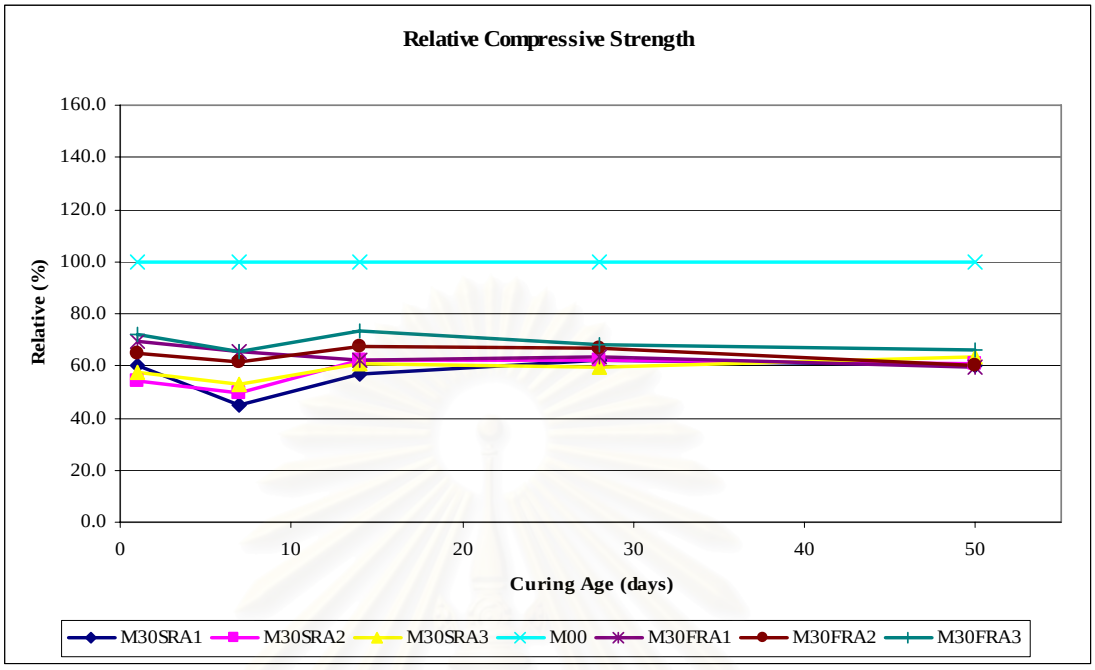

Figure 4.19 Relative Compressive Strength Developments of Cement Mortars (M30) Compared to that of Control Cement Mortar at the Same Age

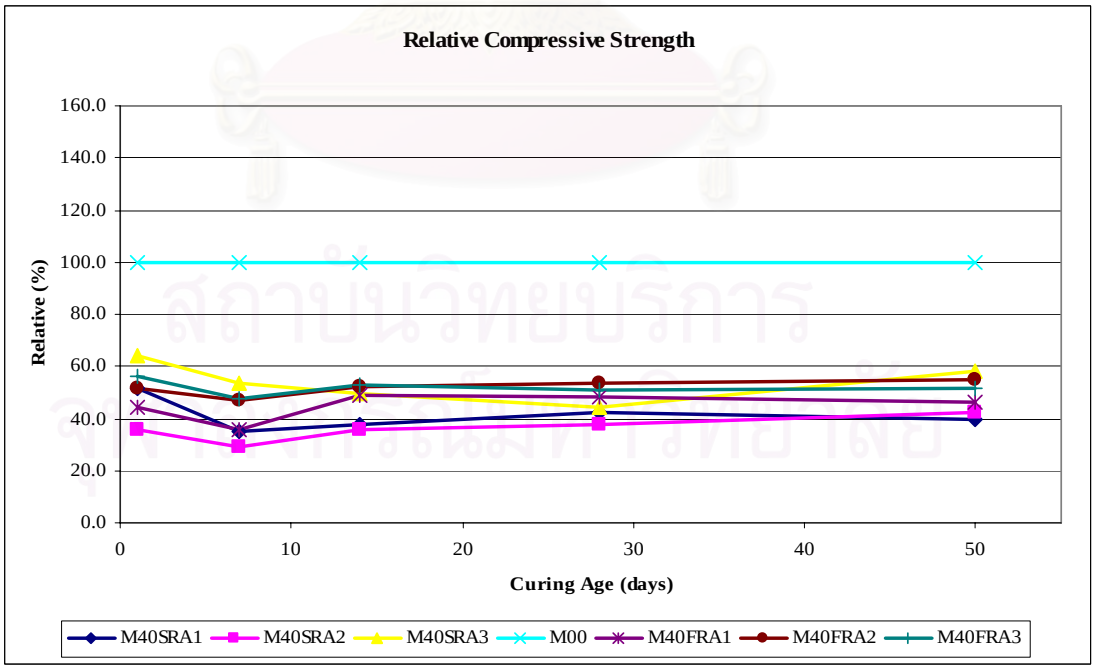

Figure 4.20 Relative Compressive Strength Developments of Cement Mortars (M40) Compared to that of Control Cement Mortar at the Same Age

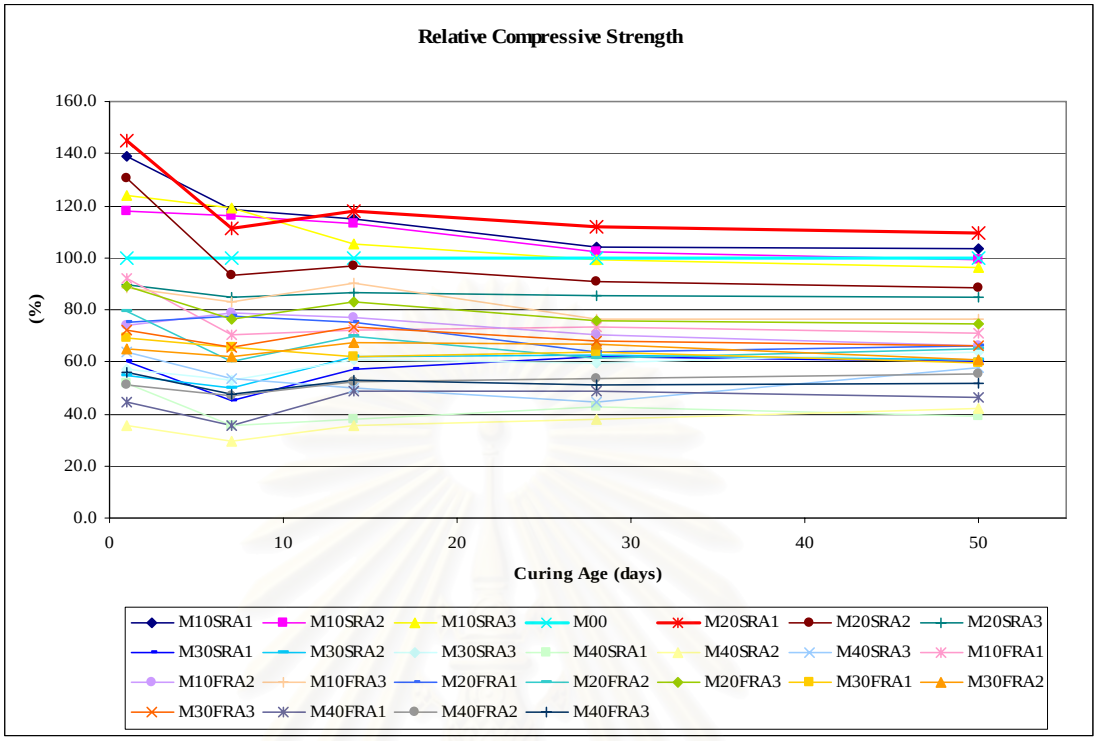

Figure 4.21 Relative Compressive Strength Developments of All Cement Mortars Compared to that of Control Cement Mortar at the Same Age

The rate of compressive strength development can be explained in Figures 4.12 to 4.16. During the first period, first to seventh day, the compressive strengths increased dramatically. After that, it can be seen the rate of compressive strength development were somehow retarded by addition of the recycled aggregates. The more natural aggregate was replaced by the recycled aggregates, the slower rate of compressive strength development. If we compared the rate of compressive strength development of recycled aggregate cement mortars with that of the control cement mortar. It can be assessed from slopes of each curve in Figures 4.12 to 4.16, easier identified in Figures 4.17 to 4.21. The recycled aggregate retarded the strength development during the first period of hydration (1-7 days). After seventh day, the rate of strength development increased and later became steady.

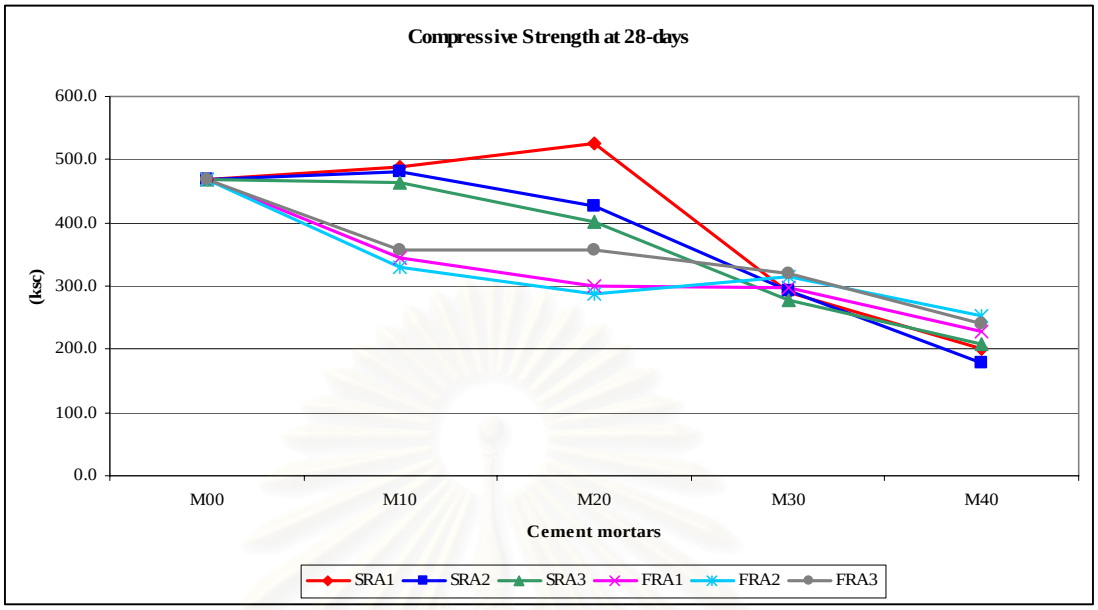

Figure 4.22 Compressive Strengths of Cement Mortars Compared to Each Proportion of Aggregate Replacement at 28-days of Curing Age

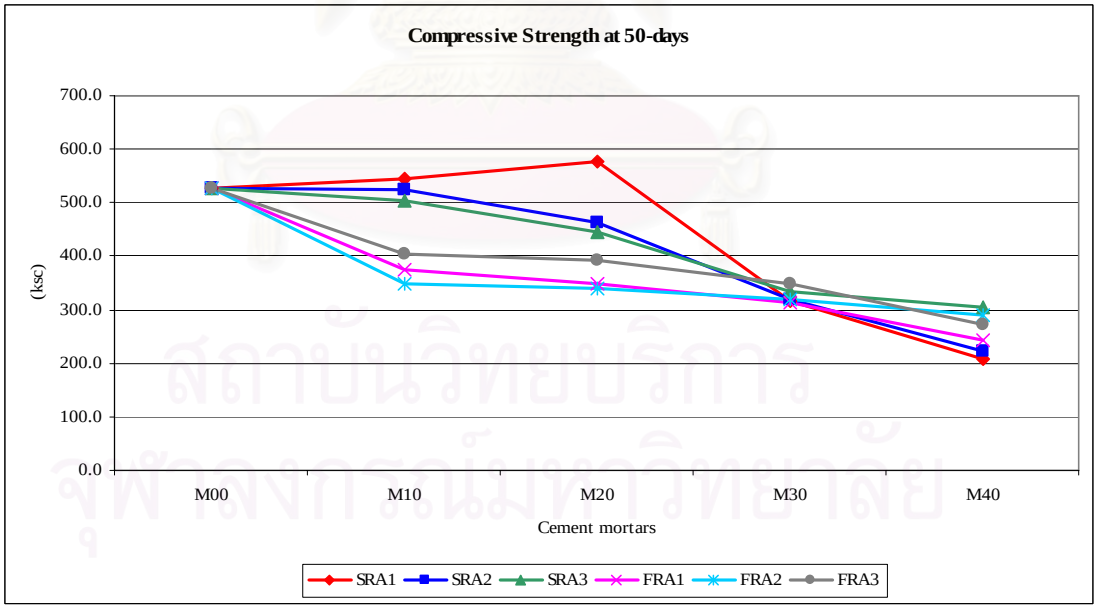

Figure 4.23 Compressive Strengths of Cement Mortars Compared to Each Proportion of Aggregate Replacement at 50-days of Curing Age

It should be noted that the cement mortars containing FRA had lower compressive strengths than those containing SRA in lower percent aggregate replacement. This may be due to the fact that they might have appropriate particle sizes which could fill into spaces of between cement particles and made cement mortars achieve good compaction as mentioned above. Moreover, the amount of very fine particle in FRA is more than SRA which could not fit in the spaces between cement particles. As discussed in section 4.3.4, the more very fine particles in recycled aggregate the more effects to the reduction of compressive strength.

Figures 4.22 and 4.23 reveal the compressive strengths of cement mortars containing each type of recycled aggregates at 28 and 50 days of curing. It can be seen that the compressive strength gradually decreased as higher percent of aggregate was replaced in cement mortars. Although it does not agree with SRA1 cement mortars since at 20 percent of aggregate replacement, the compressive strength was the highest. One possible explanation is that human error might be involved in term of operation techniques during processes of mixing, casting and packing or curing of specimens.

4.4.2 Leaching Test of Cement Mortars

The results from Table 4.7 could confirm that concentrations of the heavy metals in leachate via leaching test of cement mortars were within the regulatory limit in the Notification of MOI No.6 1997. Several reasons can be used to explain this phenomenon. First, the heavy metal contents in MSW stream were rather low. Second, the double S/S process that began with recycled aggregate production and followed by cement mortar production. Cement can cause heavy metal immobilization owing to alkaline environment caused by cement hydration. In addition, cement encapsulates heavy metals and/or incorporates them into solidified structure. Moreover, the high pH during the washing process may make heavy metals insoluble. These reasons can guarantee to limit or reduce the heavy metals leachability. On the other hand, it should be noted that the concentration of lead (Pb),

mercury (Hg), and selenium (Se) were rather high, but they were still within the regulatory limits.

Table 4.7 Average Concentrations of Heavy Metals in Leachate by Leaching Test of Cement Mortars Containing FRA and SRA

Element	Regulatory Limit* (mg/L)	Average Concentration (mg/L)	
		Mortars containing FRA	Mortars containing SRA
Silver (Ag)	5.0	<0.010	<0.010
Arsenic (As)	5.0	<0.100	<0.100
Barium (Ba)	100.0	1.350	1.270
Cadmium (Cd)	1.0	<0.005	<0.005
Chromium (Cr)	5.0	0.150	0.090
Mercury (Hg)	0.2	<0.010	<0.010
Lead (Pb)	5.0	0.190	0.290
Selenium (Se)	1.0	<0.100	<0.100

Note: *Notification of Ministry of Industry No.6, B.E. 2540 (1997)

Figures 4.24 and 4.25 reveal that the concentrations of Ba (barium) increased while the percent of recycled aggregate, solidified washed MSWIFA increased. Similarly, the concentration of Pb (lead) slightly increased with the increase in recycled aggregate replacing sand. The comparison between leached heavy metal concentrations from raw MSWIFA and cement mortars, the stabilization/solidification and cement hydration can reduce amount of lead due to high alkalinity of cement. On the contrary, the concentrations of Cr (chromium) are not increased as recycled aggregate replaced to sand increased. This may be explained by chromium is usually associated with non-reactive silicate matrices which have lower potential of leachability.

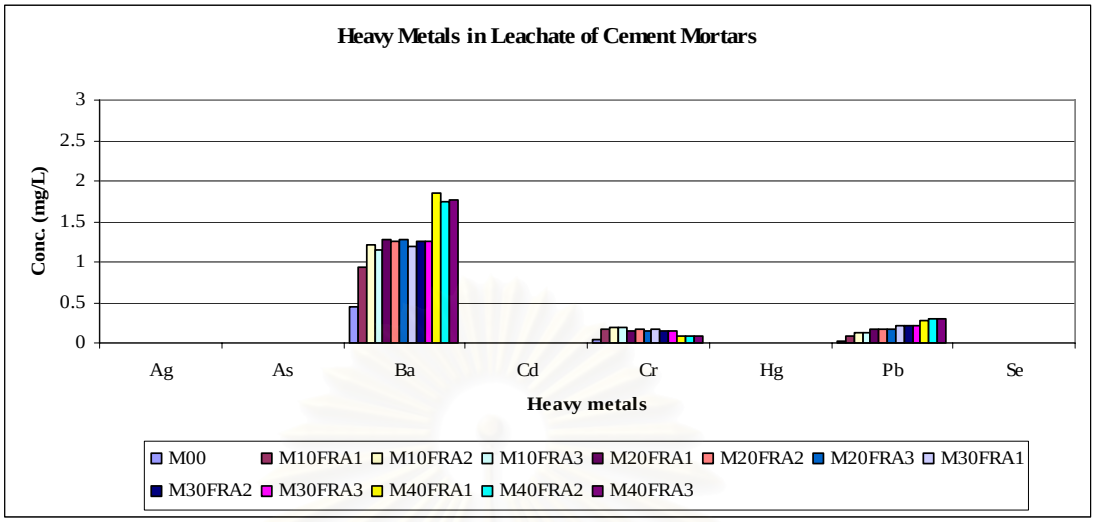

Figure 4.24 Concentrations of Heavy Metals in Leachate by Leaching Test of Cement Mortars Containing FRA

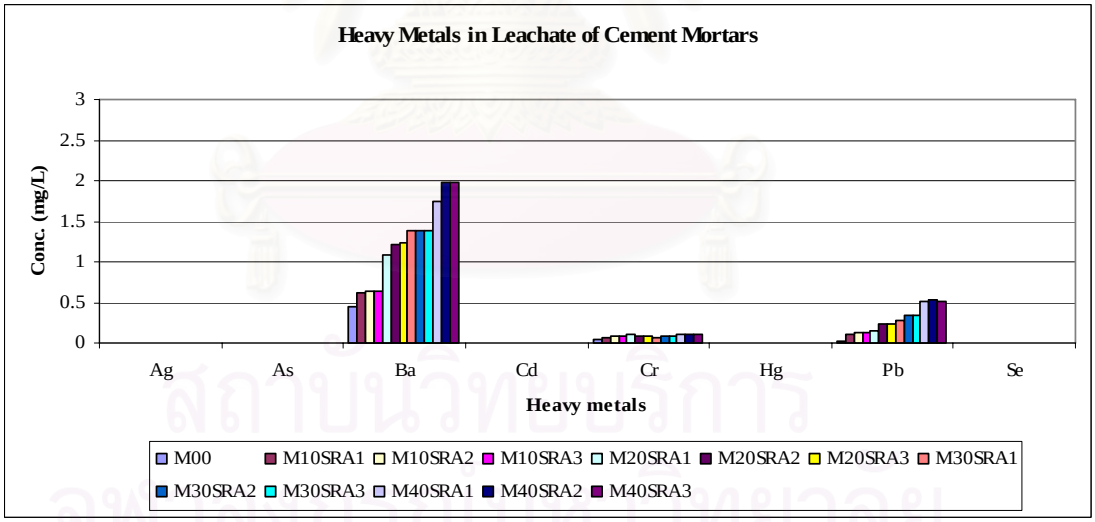

Figure 4.25 Concentrations of Heavy Metals in Leachate by Leaching Test of Cement Mortars Containing SRA

4.5 Environmental and Economical Concerns

Costs for any stabilization and solidification process as well as recycled aggregate and cement mortars production are site specific and depend upon the type of waste, pretreatment requirements, transportation distances, disposal criteria, regulatory criteria, health and safety requirements, assurance and quality control. In addition, the fluctuations in currency exchange rates make it difficult to provide specific figures. It is recommended that the cost of any treatment process are evaluated based on the relative increase in cost it may cause on the tipping fee for the incoming waste.

Table 4.8 Costs of Cement Mortars Production between Containing Natural Sand and Recycled Aggregate

General (containing Sand)					**Waste Utilization (containing SRA1+Sand)**				
	Ratio	Weight	Cost/Unit	Cost		Ratio	Weight	Cost/Unit	Cost
		kg/ 1 ton	Baht/ 1 kg	Baht			kg/ 1 ton	Baht/ 1 kg	Baht
Cement	1.00	235.00	2.10	493.50	**Cement**	1.00	235.00	2.10	493.50
Sand	2.75	647.00	0.1875	121.31	***RA***				
					-Cement	0.025	6.00	2.10	12.60
					-MSWIFA	0.25	59.00	0.00	0.00
					-Sand	2.475	582.00	0.1875	109.12
Water	0.50	118.00	0.01*	1.18	**Water**	0.50	188.00	0.01*	1.18
Total	4.25	1.00	-	*561.99*	**Total**	4.25	1.00	-	*562.40*

Note: * from Metropolitan Waterworks Authority (2006)

Table 4.8 shows the comparison between conventional cement mortars produced with natural sand and cement mortars which contain 10 percent of natural sand replacement by SRA1. The costs of production are in the same range. Though if we increase the quantity of each proportion. It would result in bigger difference. However, calculations in Table 4.8 did not include investment cost of the recycled aggregate production as well as the operation and maintenance (O&M) costs. O&M costs comprise preliminary treatment of MSWIFA costs and treatment of wastewater resulting from it, S/S costs whether or transportation costs of raw materials. Moreover, the waste utilization does not offset the cost of MSWIFA management when it is disposed of in landfill as well as cost of landfill management.

The major issue that should be discussed is waste transformation in the preliminary treatment process. Due to washing process, soluble heavy metals from raw MSWIFA dissolved into wash waster at high concentrations, thus exceeding the regulatory limits. Therefore, it is necessary to treat the wash water to reduce their heavy metal concentrations before discharge to the environment. Evidently, a wastewater treatment facility which has at least pH neutralization unit and physicochemical process unit for pH adjustment and heavy metals removal should be installed. The cost of production will be also increased by cost of chemicals and cost of wastewater treatment facility construction. Nevertheless, we can corporate with Phuket municipal wastewater treatment plant to incorporate or adapt old unit to have an ability to treat our wastewater. It can reduce cost of new unit construction and cost of operation too.

Although the costs of these two cases are not much different, but if we are more concerned in term of environmental management, the waste utilization presents a good alternative to solving the current problems of ash management. Moreover, the government or local administration organization should be involved by putting a strong emphasis on the environmental and waste management policy in terms of capital investment for companies, laws and regulations, and tax incentive to attract new manufacturers. For example, use of MSWIFA as partial admixture in local roadways, set new waste management laws, and lower or free tax for reuse and

recycle industry. These options are only a number of alternatives to help and solve the MSW and residue ash management.

CHAPTER V

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

5.1 Conclusions

This research was conducted to evaluate the potential utilization of MSWIFA as a partial aggregate replacement material in concrete products. The characterization of raw MSWIFA was carried out. After that the preliminary treatment of MSWIFA was done to produce recycled aggregate and for concrete applications. The cement mortar production which utilized recycled aggregates was carried out to define advantages of utilization over conventional practice. Finally, heavy metal leachability was observed to guarantee that the products would not cause harm to human health and the environment. The following conclusions could be drawn from this study.

5.1.1 Characteristics of MSWIFA

1. MSWIFA was characterized as very fine particles due to the result of particle size distribution. It was found that non-sprayed fly ash (FA) and sprayed fly ash (SFA) had mean particle size ($d_{50\%}$) of approximately 50 μm and 70 μm, respectively. SFA was somewhat bigger than FA because of application of water for fugitive dust control. It is consistent with the moisture contents of SFA that was higher than that of FA. LOI of FA, SFA, washed FA, and washed SFA were 3.86%, 5.09%, 4.92% and 5.14%, respectively.
2. The major chemical compositions of MSWIFA, analyzed by the XRF, are CaO and Cl. This was due to the air pollution control process of the Phuket MSW incinerator that injected lime to neutralize flue gases. Less amount of Cl was present in the washed

MSWIFA owing to the washing process. It is consistent with the result of XRD spectrometer that shows reduction in Cl compound after washing MSWIFA with water. It should be noted that similar compounds were detected in FA and SFA.

3. The heavy metals in MSWIFA existed in low quantities. However, the leachate from leaching test of MSWIFA contained lead concentration that exceeded the regulatory limit of 5 mg/L.

5.1.2 Preliminary Treatment of MSWIFA

1. Chloride is a major element in both of FA and SFA, due to washing process, chloride were detected at high concentration in both FA or SFA.
2. The concentrations of lead (Pb), selenium (Se), and barium (Ba) in washed water exceeded the limits while the concentrations of mercury (Hg) was close to the limit as well. All of concentrations were in line with the amount of heavy metals in raw MSWIFA and concentrations of heavy metals in leachate of MSWIFA.
3. The concentrations of lead (Pb), selenium (Se), and barium (Ba) in washed MSWIFA leachate exceed the limit. It is noticed that the concentrations of heavy metals in leachate of washed FA and washed SFA are slight higher than leachate of raw FA and SFA because some fractions are dissolved out of the sample.

5.1.3 Characteristics of Recycled Aggregate

1. It can be explained that all types of recycled aggregate, FRA1 to FRA3 and SRA1 to SRA3, did not meet the ASTM recommended values on particle size ranges since the particle sizes of all recycled aggregates were mostly smaller than the recommended values. F.M. values of recycled aggregates are lower than that of natural sand.

2. Organic compounds in the MSWI samples were destroyed via high temperature in combustion chamber of the incinerator. It can guarantee the organic substances did not exist in MSWIFA. Moreover, the S/S process of recycled aggregate production probably encapsulates the organic substances into the solid phase.
3. Weight loss of Recycled aggregates was minimal when they were submerged in sodium sulphate (Na_2SO_4) solution. That means the recycled aggregates have good soundness and should be suitable to be used as an inert material in concrete product. By the way, the soundness of recycled aggregate probably comes from properties of cement hydration reaction during stabilization and solidification process (S/S).
4. There are more fine materials (< 75μ) in all types of recycled aggregates than the recommended values. It is consistent with the results from sieve analysis and F.M. value. The reason for this is the fact that control of particle sizes is difficult via crushing of solidified samples by hand.

5.1.4 Properties of Cement Mortars containing Recycled Aggregate

It can be seen that the 28-day compressive strengths of M10 series are the highest. Furthermore, the M20 SRA1 got the highest compressive strength even when comparing with the control cement mortar, M00. That is 11.9% higher than the control. For other mixed proportions, the higher percentage of recycled aggregate replaced to sand, the lower the compressive strength would be.

5.1.5 Leachate Characteristics of Recycled Aggregate Cement Mortars Product

All of concentrations of leached heavy metals from recycled aggregate cement mortar specimens were within the regulatory limits following the Notification of MOI No.6 B.E.2540 (1997). However, the concentrations of barium (Ba),

chromium (Cr), and lead (Pb) were detected at significant levels. On the heavy metal concentrations in the leachates of solidified MSWIFA product were lower than raw MSWIFA because of stabilization and solidification mechanism.

5.2 Recommendations

This research performs the feasibility study of utilization of a waste in order to convert it into recyclable material. It can be concluded that after a pretreatment process the MSWIFA can be used as an ingredient in cement mortar or concrete production . Moreover, in some cases, it may produce higher compressive strength than general practice. Use of recycled aggregate in cement mortars can guarantee the safety of human health and environment as evident by the regulatory leaching test. Due to daily increase of MSWIFA, the new alternative of waste utilization should be concerned. A government or Local Administration Organization should be willing to encourage new manufacturers to invest in waste management via such means as subsidies and tax incentives. These will not only solve our problems of excess amount of waste, but also help to develop a new knowledge and technology in waste management and utilization through new researches.

The heavy metal concentrations found in wash water from the washing process exceeded the regulatory limits (the Notification of MOI No.6, 1997). If MSWIFA aggregate production were to be operated, construction of a wastewater treatment plant designed to remove heavy metals should be constructed. This unit must have a function of pH neutralization and physicochemical process for pH adjusting and heavy metals removal, respectively. Therefore, the cost for production of the solidified MSWIFA cements mortars or recycled aggregate cement mortars does not only include cost of pretreatment of raw MSWIFA, but also cost of wastewater treatment. The cost of wastewater treatment from washing process consists of those of chemicals, for pH adjustment and heavy metal removal, and construction and operation system.

5.3 Suggestions for Future Works

1. Seasonal sampling of MSWIFA should be considered to address the variation in chemical compositions of MSWIFA, due to the fluctuations in waste feed composition, burning condition, and operation of air pollution control device.
2. Mechanisms of solidified MSWIFA, both non-sprayed and sprayed fly ash should be investigated to study its effect on compressive strength of cement mortars.
3. Combined utilization of MSWIFA by cement and aggregate replacement should be performed to increase the profit of utilization.
4. Other engineering properties of solidified MSWIFA cement mortars product should be investigated, such as shrinkage, bending strength, and acid resistance.
5. Specially designed leaching test that simulates long-term use of concrete containing the recycled aggregate should be performed to guarantee the environmental and health safety.

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APPENDICES

APPENDIX A

Table A-1 Municipal Solid Waste Compositions in Thailand, 2004

Type	Quantity (%)
Food Leaving/Organic Waste	63.5
Glass	3.47
Plastic	16.83
Metal	2.1
Paper	8.19
Clothes	1.37
Wood	0.74
Rubber/Leather	0.5
Others	3.23

Source: Pollution Control Department (PCD), Ministry of Natural Resources and Environment, Thailand State of Pollution Report 2004

Table A-2
Input Amount of Solid Waste and Amount of Bottom and Fly Ash of Phuket Incinerator
During 11 Feb 2005 - 4 Feb 2006

Month	Date	Amount of solid waste excluding water (tons)	Amount of waste excluding water			Amount of ashes (tons)		Average combusted MSW excluding water	
			Combusted (tons)	Non-combusted (tons)	Average incinerated (tons/day)	Bottom ash	Fly ash	(days)	(tons/day)
1	11Feb05 - 11Mar05	9,626.55	8,340.74	2,799.03	278.02	1,540.83	279.37	30	
2	12Mar05 - 10Apr05	9,386.42	8,414.22	2,833.25	280.47	1,951.78	166.75	30	
3	11Apr05 - 10May05	9,957.45	5,886.17	2,951.14	196.21	1,227.70	119.25	24	
4	11May05 - 9Jun05	10,207.56	8,384.78	3,493.77	279.49	1,622.97	178.10	30	
5	10Jun05 - 9Jul05	10,232.13	8,365.45	3,602.21	278.85	1,724.79	151.43	30	
6	10Jul05 - 8Aug05	10,124.90	7,964.38	4,143.58	265.48	1,844.74	150.89	30	
7	9Aug05 - 7Sep05	9,906.07	6,856.27	4,037.96	228.54	1,456.67	150.43	26	
8	8Sep05 - 7Oct05	10,228.94	5,573.30	4,609.15	185.78	1,532.56	112.71	23	
9	8Oct05 - 6Nov05	10,746.13	5,155.74	4,570.02	245.51	1,045.97	157.55	21	
10	7Nov05 - 6Dec05	10,911.70	7,450.77	3,178.36	248.36	1,727.55	165.67	30	
11	7Dec05 - 5Jan06	10,474.03	7,512.49	3,455.72	250.42	1,517.02	150.33	30	
12	6Jan06 - 4Feb06	9,120.32	7,887.57	2,604.35	262.92	1,818.04	152.12	30	
Total		120,922.20	87,791.88			19,010.62	1,934.60	334	262.85
Average(tons/month)		10,076.85	7,315.99			1,584.22	161		
Percent			72.601954			15.72	1.60		

Conclusion

1. Amount of solid waste excluding water: total 120,922.20 tons, average 10,076.85 tons/month
2. Amount of combusted solid waste: total 87,791.88 tons, average 7,315.99 tons/month
3. Amount of bottom ash: total 19,010.62 tons, average 1,584.22 tons/month or 15.72 %
4. Amount of fly ash: total 1,934.60 tons, average 121 tons/month or 1.60 %
5. Average combusted solid waste excluding water 262.85 tons/day

APPENDIX B

Figure B-1 Bruker Powder X-ray Diffraction Spectrometer Model D8 Advance

Figure B-2 PANalytical X-ray Fluorescence Spectrometer model Axios System

Figure B-3 Particle Size Analyzer Model Mastersizer 2000 and Scirocco 2000

Figure B-4 Lab Mixer

Figure B-5 Rotary Agitator

Figure B-6 Compressive Strength Test Machine

Figure B-7 Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) Model Vista-MPX

Figure B-8 Microwave Digestion Model ETHOS SEL

APPENDIX C

Figure C-1 Cement Mortars Containing Recycled Aggregate
Left: Control Cement Mortar
Center: Cement Mortar containing SFA
Right: Cement Mortar containing FRA

Table C-1 Compressive Strength Development of Cement Mortars Containing SRA

Mortar	RA type	Compressive strength (ksc) at each curing age (days)				
		1	**7**	**14**	**28**	**50**
M00	-	*172.1*	*337.2*	*385.3*	*468.9*	*526.0*
M10	SRA1	239.3	398.8	443.2	488.5	545.6
	SRA2	202.7	390.6	436.3	480.3	523.1
	SRA3	213.3	401.6	406.5	464.8	504.8
M20	SRA1	249.5	375.1	453.8	524.8	576.2
	SRA2	224.3	315.2	373.1	426.0	464.0
	SRA3	154.1	286.6	334.4	401.6	446.5
M30	SRA1	103.2	151.7	219.4	290.7	315.2
	SRA2	93.8	168.0	239.8	292.8	320.1
	SRA3	98.7	178.6	235.2	278.1	334.4
M40	SRA1	88.9	119.1	146.0	199.8	207.1
	SRA2	61.2	99.1	137.4	177.4	221.4
	SRA3	110.1	180.6	191.6	209.0	305.0

Note: Each value was calculated from mean of 3 compressive strength values in acceptable range of mean ± 10%

Table C-2 Compressive Strength Development of Cement Mortars Containing FRA

Mortar	RA type	Compressive strength (ksc) at each curing age (days)				
		1	**7**	**14**	**28**	**50**
M00	-	*172.1*	*337.2*	*385.3*	*468.9*	526.0
M10	FRA1	158.2	237.3	278.1	343.7	373.9
	FRA2	127.2	266.3	297.7	329.1	349.4
	FRA3	152.1	280.5	346.6	358.0	402.9
M20	FRA1	129.3	261.0	288.7	298.9	348.6
	FRA2	136.6	202.7	268.3	288.7	340.5
	FRA3	152.9	256.9	320.1	356.0	393.5
M30	FRA1	119.1	221.0	239.8	297.7	311.9
	FRA2	111.3	208.0	258.9	314.0	318.0
	FRA3	124.4	221.4	283.4	320.1	348.6
M40	FRA1	76.7	120.3	187.6	277.1	242.6
	FRA2	88.5	157.8	201.8	252.0	289.5
	FRA3	96.6	161.1	203.1	239.8	272.4

Note: Each value was calculated from mean of 3 compressive strength values in acceptable range of mean ± 10%

Table C-3 Relative Compressive Strength Development of Cement Mortars Containing SRA Compared to Control Cement Mortars at the Same Age

Mortar	RA type	Compressive strength (ksc) at each curing age (days)				
		1	**7**	**14**	**28**	**50**
M00	-	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*
M10	SRA1	139.0	118.3	115.0	104.2	*103.7*
	SRA2	117.8	115.8	113.2	102.4	99.5
	SRA3	123.9	119.1	105.5	99.1	96.0
M20	SRA1	145.0	111.2	117.8	111.9	109.5
	SRA2	130.3	93.5	96.8	90.9	88.2
	SRA3	89.5	85.0	86.8	85.6	84.9
M30	SRA1	60.0	45.0	56.9	62.0	59.9
	SRA2	54.5	49.8	62.2	62.4	60.9
	SRA3	57.4	53.0	61.0	59.3	63.6
M40	SRA1	51.7	35.3	37.9	42.6	39.4
	SRA2	35.6	29.4	35.7	37.8	42.1
	SRA3	64.0	53.6	49.7	44.6	58.0

Table C-4 Relative Compressive Strength Development of Cement Mortars Containing FRA Compared to Control Cement Mortars at the Same Age

Mortar	RA type	Compressive strength (ksc) at each curing age (days)				
		1	**7**	**14**	**28**	**50**
M00	-	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*
M10	FRA1	91.9	70.4	72.2	73.3	71.1
	FRA2	73.9	79.0	77.3	70.2	66.4
	FRA3	88.4	83.2	90.0	76.3	76.6
M20	FRA1	75.1	77.4	74.9	63.7	66.3
	FRA2	79.4	60.1	69.6	61.6	64.7
	FRA3	88.8	76.2	83.1	75.9	74.8
M30	FRA1	69.2	65.5	62.2	63.5	59.3
	FRA2	64.7	61.7	67.2	67.0	60.5
	FRA3	72.3	65.7	73.6	68.3	66.3
M40	FRA1	44.6	35.7	48.7	59.1	46.1
	FRA2	51.4	46.8	52.4	53.7	55.0
	FRA3	56.1	47.8	52.7	51.1	51.8

BIOGRAPHY

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