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AN INITIAL INVESTIGATION OF THE USE OF LOCAL INDUSTRIAL WASTES AND BY-PRODUCTS AS MINERAL FILLERS IN STONE MASTIC ASPHALT PAVEMENTS

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ABSTRACT

Environmental awareness of the drawbacks of landfill sites is forcing nations to look for better ways to recycle and Increase usage of industrial wastes and by-products will both decrease the demand for available materials and help solve many disposal problems. The use of industrial wastes and by-products as Mineral fillers in asphalt mixtures is not a new technique. Mineral Fillers have been used in road construction for many years. They are incorporated in asphalt mixtures to enhance the properties and performance of asphalt concrete pavements. Mineral fillers vary in mineralogy, chemical properties, shape and texture, size, and gradation. The major objective of this initial investigation was to find out whether it is possible to use the local industrial and by-products wastes such as Steel slag, Ceramic waste, Coal fly ash, limestone, and Rejected ceramic raw material as mineral fillers in Stone Mastic Asphalt (SMA) mixtures in Malaysia. Chemical analysis using Scanning Electro Microscope (SEM), Energy Dispersive X-ray (EDX) and physical tests were performed on those local industrial and by-products wastes specimens to determine its chemical composition, size and shape of particles, as well as gradation and specific gravity, and were compared to limestone dust the common type of mineral filler used in Stone Mastic Asphalt in Malaysia. The test results indicate that the physical and chemical properties of the local industrial wastes are within specified limits of quality requirements for mineral filler for Bituminous Paving Mixtures AASHTO M17, and in accordance with AASHTO PP41 (Designing of Stone Matrix Asphalt) and these waste materials can potentially be used as mineral fillers in Stone Mastic Asphalt (SMA) Mixtures.

Keywords: industrial wastes, mineralogy, chemical properties, mineral filler, SMA pavement mixtures.

INTRODUCTION

In developed countries, industrial wastes disposal is a major problem and some of these wastes are burned in incinerators and the residue are land filled. The use of waste and by-products materials in the construction of pavements has benefits in not only reducing the amount of waste materials requiring disposal but can provide construction materials with significant savings over new materials. The use of these materials can actually provide value to what was once a costly disposal problem. Using industrial wastes in the asphalt concrete pavement can not only decrease environmental problems but also improves some properties of the pavement

The industrial wastes could be used to form a structural component of the pavement. Some have uses as replacements for conventional aggregates and some form part or all of the binder in the particular mixture.

Existing hot mix asphalt design and analysis procedures are often inappropriate for mixtures containing waste materials; therefore, procedures must be developed to provide for their consistently successful application (Terrel *et al*., 1994).

Stone Matrix Asphalt (SMA) is a premium type of hot mix asphalt pavement. One of the component ingredients in SMA mixtures is mineral filler. More than 8-10% of asphalt pavement materials (by weight of aggregate) consist of mineral fillers in SMA mixtures.

Mineral fillers combine with the asphalt, fibers, and a small percentage of fine aggregate particles to create binder rich mastic which fills the void spaces between the coarse aggregate skeleton. The requirements for mineral filler are not complex. Consequently, a variety of materials have been used as mineral fillers in SMA including rock dust products of various mineralogy, fly ash, Portland cement, kiln dusts, and limestone.

As defined in most of the road standard, mineral fillers are considered part of the aggregate and are partially defined as consisting of "finely divided mineral matter such as rock dust, slag dust, hydrated lime, hydraulic cement, fly ash, loess, or other suitable mineral matter. Fillers play an important role in stabilizing the hot mix asphalt (HMA) by filling the voids within the larger aggregate particles, and improving the consistency of the binder that cements the larger aggregate particles (Puzinauskas, 1969).

Furthermore, they affect the workability, moisture sensitivity, stiffness, and aging characteristics of HMA (Mogawer and Stuart, 1996). The effect of fillers is more prominent in gap-graded asphalt mixtures, such as the Stone Matrix Asphalt (SMA) mixture that contains large amounts of fines. Typical filler completely passes a 0.60 mm (No.30) sieve, with at least 65-70 percent by weight of the particles passing the 0.075 mm (No.200) sieve.

The purpose of this initial investigation was to determine the feasibility of utilizing the local Malaysian industrial and by-products wastes such as Steel slag, Ceramic waste, Coal fly ash, limestone, and Rejected ceramic raw material as mineral fillers in Stone Mastic Asphalt (SMA) mixtures.

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MATERIALS

Coal fly ash (CFA)

Fly ash is produced by coal-fired electric and steam generating plants. Typically, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue. Boiler tubes extract heat from the boiler, cooling the flue gas and causing the molten mineral residue to harden and form ash. Coarse ash particles, referred to as bottom ash or slag, fall to the bottom of the combustion chamber, while the lighter fine ash particles, termed fly ash, remain suspended in the flue gas. Prior to exhausting the flue gas, fly ash is removed by particulate emission control devices, such as electrostatic precipitators or filter fabric baghouses.

The Coal Fly Ash used in this study was obtained from The Manjung coal-fired power plant, Lumut, Perak, Malaysia which uses low sulphur and low bitumen coal (pulverized for burning) to minimize pollution. The resulting ash is valuable for the cement industry, and most is caught by electrostatic precipitators. Dust control is also an important feature (the conveyor belt is covered and sprinkler systems remove up to 99.9%).

The unique spherical shape and particle size distribution of fly ash make it good mineral filler in hot mix asphalt (HMA) applications and improves the fluidity of flowable fill and grout. The consistency and abundance of fly ash in many areas present unique opportunities for use in structural fills and other highway applications.

This fly ash is a fine silt size material consisting of spherical glassy particles and is composed of 54.57% silicon oxide, 8.24% aluminum oxide, 14.28% iron, and 6.85% calcium. The total amount of silicon, aluminum and iron oxides is 77.09%. The minimum acceptable requirement is 50% to be a type C fly ash (Conner, 1990). Figure-1 shows a sample of fly ash color.

Figure-1. Typical ash colors.

Limestone dust (LSD)

Limestone is a sedimentary rock composed largely of the mineral calcite (calcium carbonate: $CaCO_3$) as shown in Figure-2. Limestone is a naturally occurring and abundant sedimentary rock consisting of high levels of calcium and/or magnesium carbonate, and/or dolomite (calcium and magnesium carbonate), along with small amounts of other minerals. It is extracted from quarries and underground mines all over the world. Limestone dust is one of typical type of filler used in Malaysian road industry. This material is easily available and quality is certainly proven due to the production are already established and commercialized.

Limestone is widely used as crushed stone, or aggregate, for general building purposes, roadbeds and railway lines. Finely crushed limestone is also used as filler in industrial products such as asphalt, rubber, plastic, and fertilizers. When heated, the calcium carbonate in limestone decomposes to lime, or calcium oxide, and is important as a flux in smelting copper and lead ores and in making iron and steel. Lime is a key ingredient in the manufacture of cement and concrete. In this study the limestone filler obtained from CSI Industry, a sample was collected from the supplier and was quartered into smaller representative portion for sieve analysis, physical and chemical test.

Figure-2. A sample of calcium carbonate ($CaCO_3$). limestone filler.

Ceramic waste (CWD)

It has been estimated that about 30% of the daily production in the ceramic industry goes to waste. This waste is not recycled in any form at present. However, the ceramic waste is durable, hard and highly resistant to biological, chemical and physical degradation forces. As the ceramic waste is piling up everyday, there is pressure on the ceramic industries to find a solution for its disposal. Ceramic waste consists of china and porcelain from old or defective manufactured objects (Collins and Ciesielski, 1994). The ceramic waste used in this study was obtained from M/s Seacera Tiles Berhad, Lot 16428, and 14km Jalan Ipoh, Kawasan Perindustrian Selayang, Batu Caves, Selangor, Malaysia.

Steel Slag (SSD)

Steel slag blast-furnace (iron) and steel slag. Iron ore, coke, and limestone are superheated in a blast furnace to produce pig iron. A waste product of this procedure is blast-furnace slag, which essentially consists mainly of

silicates and alumino-silicates of lime (Ahmed, 1991 and Collins and Ciesielski, 1994). The Steel Slag used in this study was obtained from M/s Perwaja Steel Berhad, Kemaman Plant, Kemaman, Terengganu, Malaysia. The annual capacity of this Plant was 800,000MT Billet, 700,000MT Beam Blanks Bloom. The main production process was Direct Reduction Plant, EAF and Continuous Casting, Rolling Mill. The Annual waste of the steel slag alone from this Plant was approximately 200,000 MT.

Rejected ceramic raw material (RCRM)

The majority of raw materials used by the ceramic industry are the oxides of metals. The three metals which have been the mainstays of the industry for many years are clay (hydrated alumino-silicates), flint (a form of silicon dioxide, SiO_2), and feldspar or flux (alkali-alumino-silicates). These are the major materials contained in what is sometimes referred to in the industry as "classical ceramic bodies."

The Rejected (too coarse or too fine) Ceramic raw material used in this study was obtained from M/s Seacera Tiles Berhad, Lot 16428, and 14km Jalan Ipoh, Kawasan Perindustrian Selayang, Batu Caves, Selangor, Malaysia.

EXPERIMENTS

The experiments were conducted at the laboratories of the Department of Civil Engineering, University Putra Malaysia (UPM), Serdang, Malaysia.

Coal fly ash, Limestone, Ceramic waste, Steel slag, and Rejected ceramic raw materials were analyzed for there chemical properties using Energy Dispersive Analysis X-ray (EDX) and Scanning Electronic Microscope (SEM) and key physical characteristics of the mineral fillers including gradation, specific gravity, methlene blue, moisture content, solubility, pH value,

Fineness (percent amount retained on No. 325 Sieve (45 micron)), Plasticity Index, Surface Area, grain size, and particle shape were determined

METHODS

Sieve analysis was carried out on a representative Coal fly ash, Ceramic waste, Steel slag, and Rejected ceramic raw materials sample, along with Limestone dust (control). The dry sieve analysis was carried out according to ASTM D546 and AASHTO T37. Table-1 shows the AASHTO M17 specification requirements for mineral filler use in asphalt paving mixtures.

Standard methods were used for the determination of the physical and chemical characteristics of the industrial waste samples. The parameters analyzed were moisture content, bulk-specific gravity, percent fineness, percent soluble, pH value, plasticity index, methylene blue particle shape and size, iron, silica, alumina, calcium, magnesium, sodium, potassium, and sulfate. Scanning Electro Microscope (SEM) and Energy Dispersive X-ray (EDX) were used for the chemical composition analysis.

Table-1. AASHTO M17 specification requirements for mineral filler use in asphalt paving mixtures.

Particle sizing		Organic	Plasticity
Sieve size	Percent passing		
0.60 mm (No. 30)	100	Mineral filler must be free from any organic impurities	Mineral filler must have plasticity index not greater than 4
0.30 mm (No. 50)	95-100		
0.075mm (No. 200)	70-100		

RESULTS AND DISCUSSIONS

Properties of the fines evaluated particle size

Only the minus No. 200 sieve (0.075 mm) fractions of the fines were evaluated in this initial investigation. Particle size distributions in Table-2 were determined by the dry sieve analysis of fines using AASHTO T37 / ASTM D546 specification. Significant variations in gradation were observed for the fine samples from the various plants, as shown in Table-2 and Figure-3.

Table-2. Particle size distribution.

Sieve size µm	CFA	LSD	CWD	SSD	RCRM
	% passing				
600	100	100	100	100	100
300	99.53	95.8	91.46	71.85	93.53
75	92.2	84.56	70.86	32.59	71.42
53	74.85	68.63	49.86	22.42	54.63
20	6.7	4.7	1.92	0.76	3.45
10	0	0	0	0	0

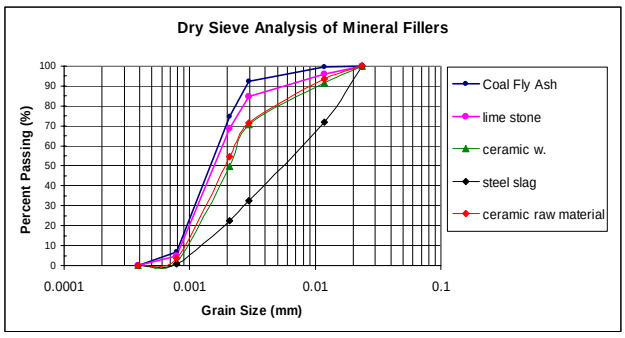

Figure-3. Dry sieve analyses of industrial wastes.

The standard specification of mineral fillers for bituminous paving mixtures (ASTM D 242-85) has the following grading requirements: 100% passing 0.600mm sieve, 95-100% passing 0.300 mm sieve, and 75-100% passing 0.075 mm. AASHTOM17-83 (1986) specification

has similar requirements for passing 0.600 and 0.300 mm but it requires 70-100% to pass 0.075 mm. According to Table-2 all materials would pass both AASHTO M17-83 and ASTM D 242-85 grading requirements except the steel slag.

Chemical (mineral) Composition

Mineral compositions of the coal fly ash, limestone dust, ceramic waste, steel slag, and rejected ceramic raw material were obtained by Energy Dispersive X-ray (EDX) and Scanning Electro Microscope (SEM).

Physical Analysis

Specific gravity, moisture content, percent fineness, methylene blue, grain size, particle shape, solubility, plasticity index, solubility and pH values of fines (after mixing the fines with an equal weight of water (pH 7) devoid of dissolved ions) were determined.

1. Coal fly ash

(a) Chemical composition

Fly ash consists primarily of oxides of silicon, aluminum iron and calcium. Magnesium, potassium, sodium, titanium, and sulfur are also present to a lesser degree (Table-3 and Figure-4).

Table-3. Chemical composition of Coal fly ash.

Chemical (elemental) analysis using EDX	**Weight %**	**ASTM C618, Class N, (Natural Pozzolan)**
Calcium Carbonate, Ca Co_3	10.33	-
*Silicon Dioxide, Si O_2	54.57	-
Magnesium Oxide, Mg O	4.22	5.0% Maximum
*Aluminum Oxide, Al2 O_3	8.24	-
Calcium, Ca	6.85	-
Titanium, Ti	0.33	-
*Iron, Fe	14.28	-
Sum of Si O_2, Al_2 O_3, Fe	77.09	70% Minimum
Feldspar, K Potassium	0.76	-
Available Alkalis as Na_2 O	-	1.5% Maximum
Sulfur Trioxide, S O_3	-	4% Minimum (ASTMC114)

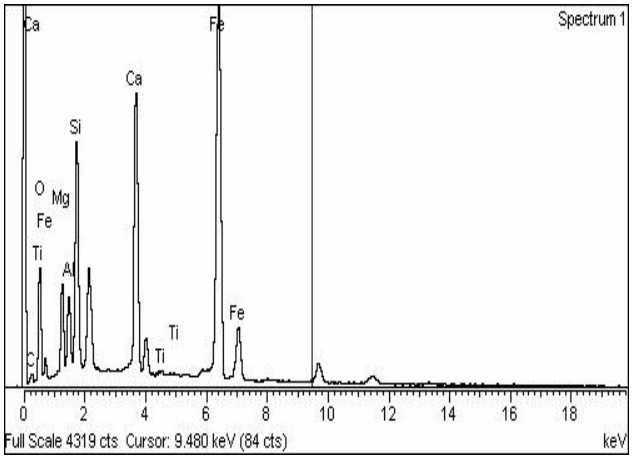

Figure-4. Chemical Composition of Coal Fly Ash.

The Chemical composition of fly ash relates directly to the mineral chemistry of the parent coal and any additional fuels or additives used in the combustion or post-combustion processes. The pollution control technology that is used can also affects the chemical composition of the fly ash. Electric generating stations burn large volumes of coal from multiple sources. Coals may be blended to maximize generation efficiency or to improve the station environmental performance.

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The chemistry of the fly ash is constantly tested and evaluated for specific use applications. Some stations selectively burn specific coals or modify their additives formulation to avoid degrading the ash quality or to impart desired fly ash chemistry and characteristics.

(b) Physical Properties

Size and Shape

Fly ash is typically finer than Portland cement and lime. Fly ash consists of silt-sized particles which are generally spherical, typically ranging in size between 10 and 100 micron (Figure-5). These small glass spheres improve the fluidity and workability of fresh concrete.

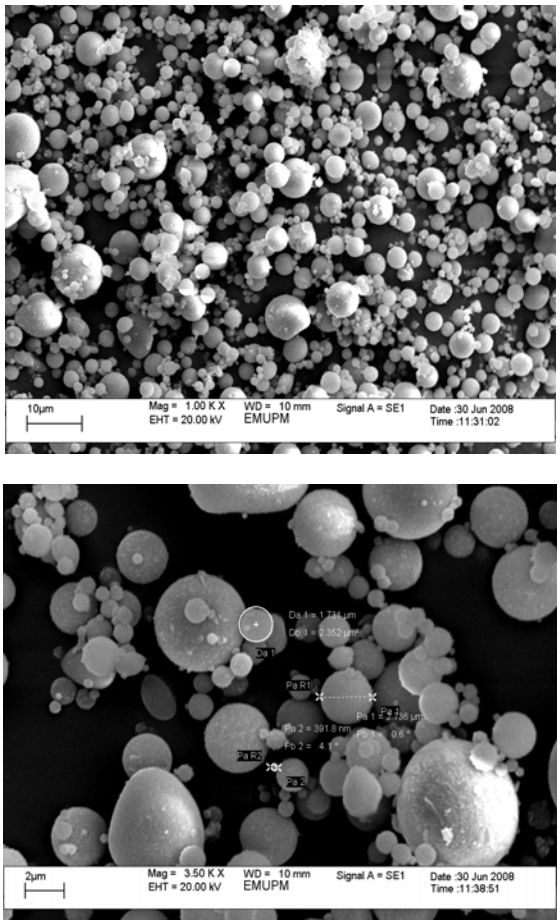

Figure-5. Fly ash particles at 1,000 x and at 3,500 x magnification.

Physical Analysis

Table-4. Physical properties of coal fly ash.

Physical analysis	**Result**	**ASTM C618, Class N**, (Natural Pozzolan)
Moisture content (%)	0.13	3.0% Max.
Specific gravity	2.63	2.1-3.0
Fineness, amount retained on No. 325 Sieve (45micron) (%)	7.37	34% Maximum ASTM C430
Grain size (Micron) using SEM	1.731 – 2.736	-
Surface area, µm2 using SEM	2.352	-
Particle shape using SEM	Spherical	-
% Insoluble	99.15	-
% Soluble	0.85	-
Methylene blue	0.90	
PH - Value @ 27ºC	10.86	
Plasticity index	NP	< 4 AASHTO M17

2. Limestone

(a) Chemical composition

Refer to Table 5 and Figure-6.

Table-5. Chemical composition of limestone dust.

Chemical (elemental) analysis using EDX	**Weight** %	**ASTM C618, Class N,** (Natural Pozzolan)
Calcium carbonate, $Ca\ Co_3$	7.27	-
*Silicon Dioxide, $Si\ O_2$	45.70	-
Magnesium Oxide, Mg O	0.45	5.0% Maximum
*Aluminum Oxide, $Al_2\ O_3$	-	-
Calcium, Ca	40.77	-
Titanium, Ti	-	-
*Iron, Fe	-	-
Sum of $Si\ O_2$, $Al_2\ O_3$, Fe	45.70	70% Minimum
Feldspar, K Potassium	-	
Available alkalis as $Na_2\ O$	-	1.5% Maximum
Sulfur Trioxide, $S\ O_3$	-	4% Minimum ASTM C114

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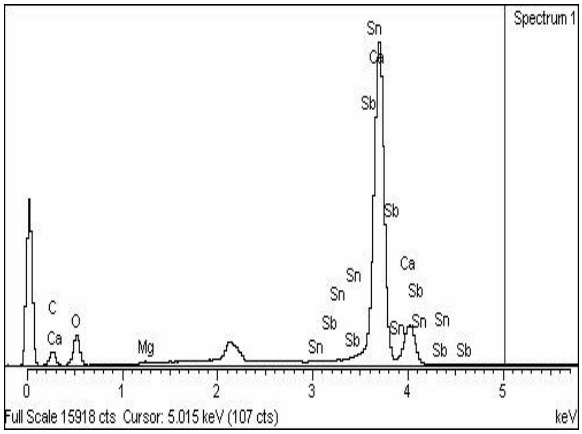


Figure-6. Chemical composition of limestone dust.

(b) Physical properties

Size and shape

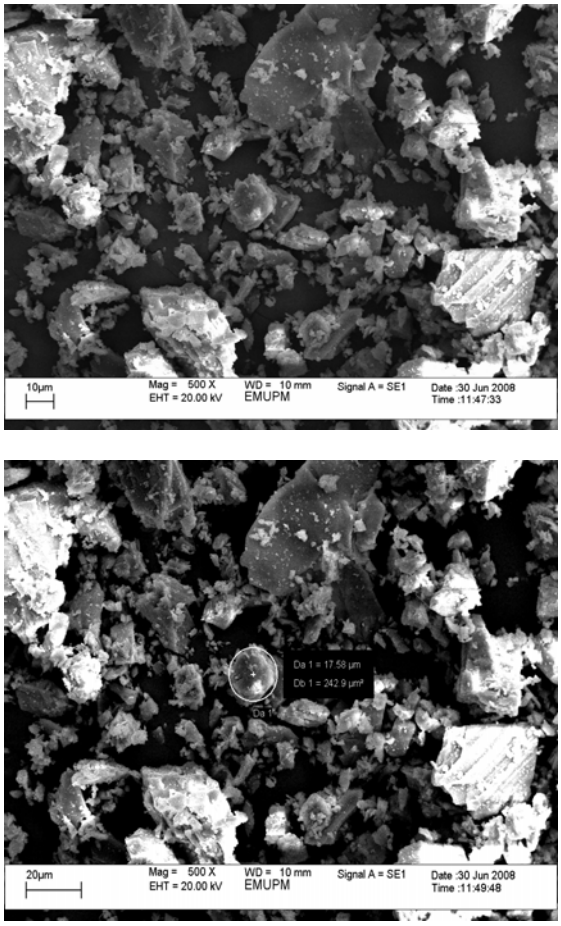


Figure-7. Grain size and particle shape of limestone dust at 500 x magnification.

Physical analysis

Table-6. Physical properties of limestone dust.

Physical analysis	**Result**	**ASTM C618, Class N, (Natural Pozzolan)**
Moisture content (%)	0.06	3.0% Maximum
Specific gravity	2.55	-
Fineness, amount retained on No. 325 Sieve 45 micron) (%)	25.03	34 % Maximum (ASTM C430)
Grain size (Micron) using SEM	17.58	-
Surface area, µm2 using SEM	242.9	-
Particle shape using SEM	flaky	-
% Insoluble	99.80	-
% Soluble	0.20	-
Methylene blue	1.2	
PH - Value @ 27ºC	9.82	
Plasticity index	NP	< 4 (AASHTOM17)

3. Ceramic waste

(a) Chemical composition

Table-7. Chemical composition of ceramic waste.

Chemical (elemental) analysis using EDX	**Weight %**	**ASTM C618, Class N, (Natural Pozzolan)**
Calcium Carbonate, $Ca\ Co_3$	8.00	-
*Silicon Dioxide, $Si\ O_2$	74.94	-
Magnesium Oxide, Mg O	0.45	5.0% Maximum
*Aluminum Oxide, $Al_2\ O_3$	8.54	-
Calcium, Ca	40.77	-
Titanium, Ti	0.31	-
*Iron, Fe	1.11	-
Sum of $Si\ O_2$, $Al_2\ O_3$, Fe	84.59	70% Minimum
Available Alkalis as $Na_2\ O$	1.55	1.5% Maximum
Sulfur Trioxide, $S\ O_3$	-	4% Minimum (ASTM C114)
Feldspar, K Potassium	2.02	-

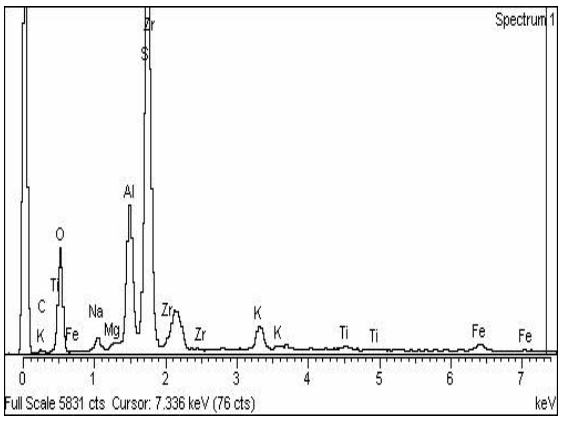


Figure-8. Chemical composition of ceramic waste.

(b) Physical properties

Size and shape

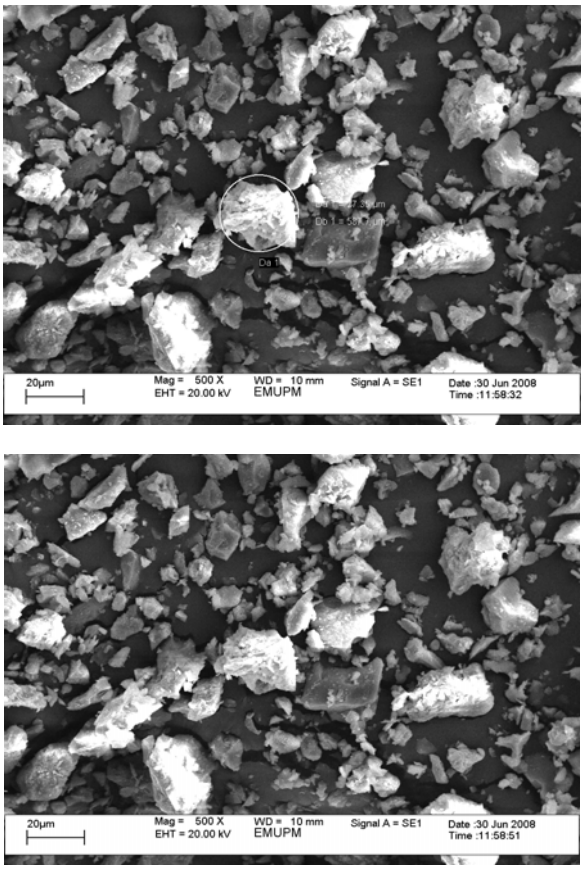


Figure-9. Grain size and particle shape of ceramic waste at 500x magnification.

Physical Analysis

Table-8. Physical properties of ceramic waste.

Physical analysis	**Result**	**ASTM C618, Class N, (Natural Pozzolan)**
Moisture content (%)	0.41	3.0% Maximum
Specific gravity	2.39	-
Fineness, amount retained on No. 325 Sieve (45 micron), %	7.07	34% Maximum ASTM C430
Grain size (Micron) using SEM	27.35	-
Surface area, µm2 using SEM	587.7	-
Particle shape using SEM	flaky	-
% Insoluble	99.69	-
% Soluble	0.30	-
Methylene blue	1.8	
PH - Value @ 27ºC	9.26	
Plasticity index	NP	< 4 (AASHTO M17)

4. Steel slag

(a) Chemical composition

Table-9. Chemical composition of steel slag.

Chemical (elemental) analysis using EDX	**Weight %**	**ASTM C618, Class N, (Natural Pozzolan)**
Calcium Carbonate, Ca Co_3	4.25	-
*Silicon Dioxide, Si O_2	41.41	-
Magnesium Oxide, Mg O	0.36	5.0% Maximum
*Aluminum Oxide, Al_2 O_3	16.71	-
Calcium, Ca	1.07	-
Titanium, Ti	0.82	-
*Iron, Fe	17.45	-
Sum of Si O_2, Al_2 O_3, Fe	95.93	70% Minimum
Manganese, Mn	0.33	
Available Alkalis as Na_2 O	0.64	1.5% Maximum
Sulfur Trioxide, S O_3	-	4% Minimum (ASTM C114)
Feldspar, K Potassium	0.38	-

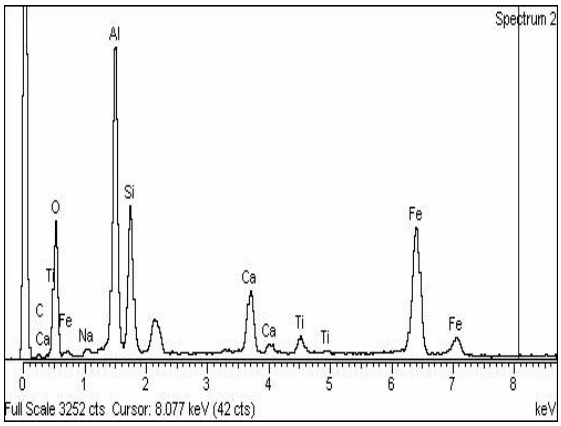
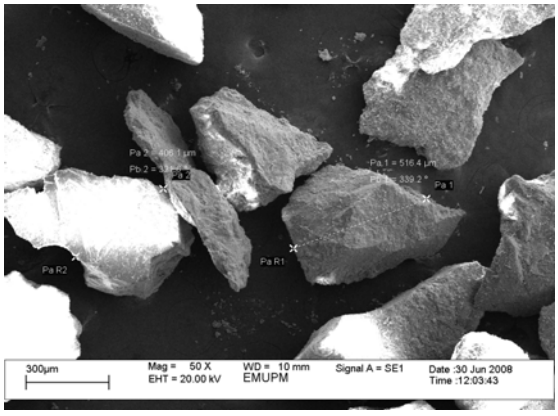


Figure-10. Chemical composition of steel slag.

(b) Physical properties

Size and shape



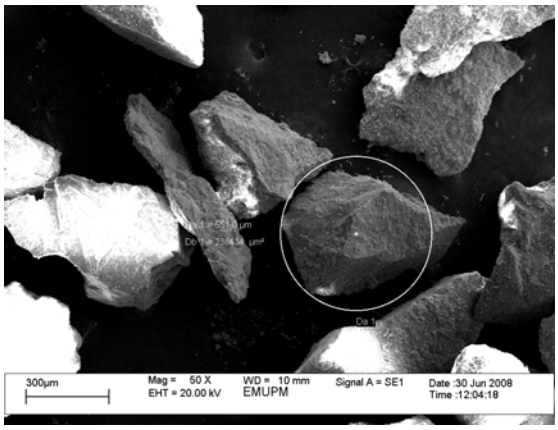


Figure-11. Grain size and particle shape of steel slag at 50x magnification.

Physical Analysis

Table-10. Physical properties of steel slag.

Physical analysis	**Result**	**ASTM C618, Class N, (Natural Pozzolan)**
Moisture content (%)	0.02	3.0 % Maximum
Loss on ignition (950ºC)	-	10.0 % Maximum ASTM C114
Specific gravity	3.4	3.2 – 3.6
Fineness, amount retained on No. 325 Sieve (45 micron), %	0.03	34% Maximum (ASTM C430)
Grain size (Micron) using SEM	516.4	-
Surface area, µm2 using SEM	238434	-
Particle shape using SEM	flaky	-
% Insoluble	99.94	-
% Soluble	0.06	-
Methylene blue	0.30	
Ph - Value @ 27ºC	9.25	
Plasticity index	NP	< 4 (AASHTO M17)

5. Rejected ceramic raw material

(a) Chemical composition

Table-11. Chemical composition of rejected ceramic raw material.

Chemical (elemental) analysis using EDX	**Weight** %	**ASTM C618, Class N,** (Natural Pozzolan)
Calcium Carbonate, Ca Co_3	7.1	-
*Silicon Dioxide, Si O_2	76.41	-
Magnesium Oxide, Mg O	0.75	5.0% Maximum
*Aluminum Oxide, Al_2 O_3	11.65	-
Calcium, Ca	0.23	-
Titanium, Ti	0.35	-
*Iron, Fe	0.91	-
Sum of Si O_2, Al_2 O_3, Fe	88.97	70% Minimum
Manganese, Mn	0.75	

Available alkalis as Na_2O	1.15	1.5% Maximum
Sulfur Trioxide, SO_3	-	4% Minimum ASTM C114
Feldspar, Potassium K	1.52	-

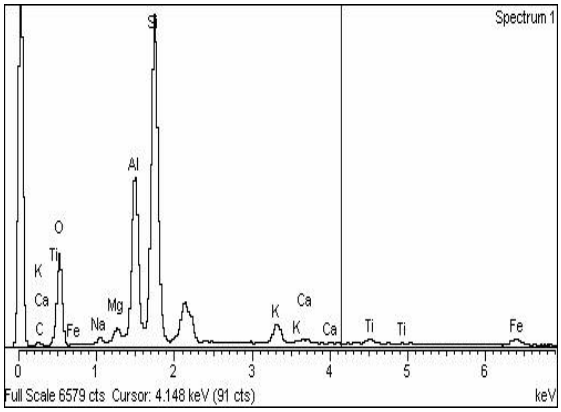
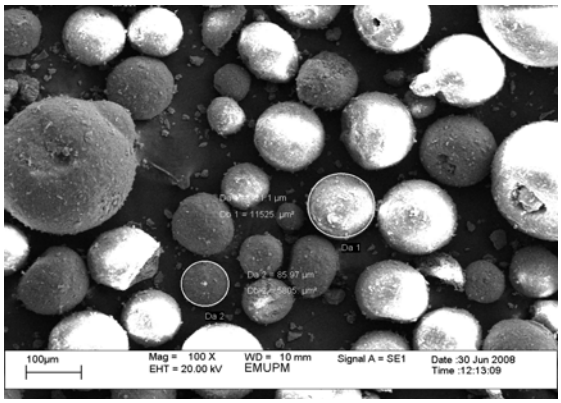


Figure-12. Chemical composition of rejected ceramic raw material.

(b) Physical composition

Size and shape



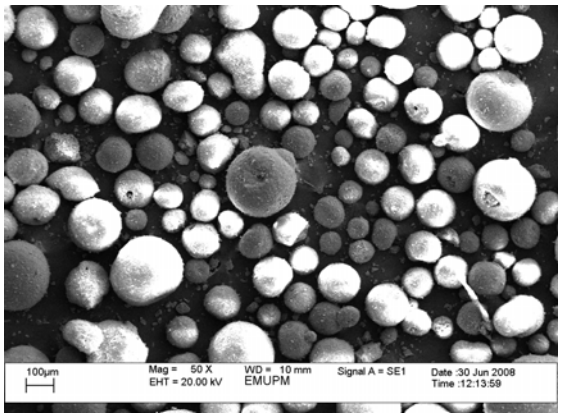


Figure-13. Grain size and particle shape of rejected ceramic raw material at 100x and 50x magnification.

Physical analysis

Table-12. Physical properties of rejected ceramic raw material.

Physical analysis	**Result**	**ASTM C618, Class N,** (Natural Pozzolan)
Moisture content (%)	0.95	3.0% Maximum
Specific gravity	2.07	-
Bulk density (Pcf loose)	-	-
Fineness, amount retained on No. 325 Sieve (45 micron), %	0.13	34% Maximum (ASTM C430)
Grain size (Micron) using SEM	85.97 – 121.1	-
Surface area, µm2 using SEM	5805 - 11525	-
Particle shape using SEM	Spherical	-
% Insoluble	99.45	-
% Soluble	0.55	-
Methylene blue	2.0	
Ph–Value @ 27ºC	8.81	
Plasticity index	NP	< 4 (AASHTO M17)

CONCLUSIONS

In this study, initial investigation was made on the chemical and physical properties to determine the suitability of the Malaysian local industrial wastes and by-products for use as mineral filler for SMA mixtures. The measurements were performed including gradation, moisture content, specific gravity, methylene blue, solubility, grain size, particle shape, pH value, percent fineness, and chemical composition. Based on the findings of the initial results, the following main conclusions can be drawn according to the results obtained:

- Laboratory tests indicate good potential for local industrial wastes and can be suitable mineral fillers for stone matrix asphalt and guaranteed to meet the requirement of SMA Mixtures;
- The gradation conformed to the gradation range specified in AASHTO M17 specification requirements for mineral filler use in asphalt paving mixtures;
- The mineral composition showed that the Sum of Si O2, Al2 O3, Fe were above the minimum requirement of ASTM C618, Class N, (Natural Pozzolan);
- The large amount utilization of industrial wastes and byproducts testified that it can be used as potential materials in road construction for saving natural resources; and

- However, not all industrial wastes and byproducts are the same and may perform differently in laboratory tests and field conditions. Some premature failures of SMA pavements have been attributed to mineral fillers while others have performed satisfactorily. The available calcium oxide content is believed to be a critical factor for whether or not the industrial wastes are suitable for use as mineral fillers.

From the above results there is a high possibility for industrial wastes and by-products to be used as fillers in asphalt concrete, and there should be further studies by conducting field tests for application of those wastes in asphalt concrete.

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