International Journal of Research in Advanced Engineering and Technology
www.newengineeringjournal.in
ISSN: 2455-0876
Received: 26-05-2022, Accepted: 11-06-2022, Published: 28-06-2022
Volume 8, Issue 1, 2022, Page No. 46-59

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
Natural consciousness of the downsides of landfill destinations is constraining countries to search for better ways of reusing and Increase utilization of modern squanders and side-effects will both lessening the interest for accessible materials and assist with tackling numerous removal issues. The utilization of modern squanders and side-effects as Mineral fillers in black-top combinations is definitely not another method. Mineral Fillers have been utilized in street development for a long time. They are consolidated in black-top blends to upgrade the properties and execution of black-top substantial asphalts. Mineral fillers fluctuate in mineralogy, substance properties, shape and surface, size, and degree. The significant goal of this underlying examination was to see if it is feasible to utilize the nearby modern and side-effects squanders, for example, Steel slag, Ceramic waste, Coal fly debris, limestone, and Rejected ceramic unrefined substance as mineral fillers in Stone Mastic Asphalt (SMA) combinations in Malaysia. Compound examination utilizing Scanning Electro Microscope (SEM), Energy Dispersive X-beam (EDX) and actual tests were performed on those nearby modern and side-effects squanders examples to decide its synthetic piece, size and state of particles, as well as degree and explicit gravity, and were contrasted with limestone dust the normal sort of mineral filler utilized in Stone Mastic Asphalt in Malaysia. The experimental outcomes demonstrate that the physical and compound properties of the neighborhood modern squanders are inside determined constraints of value necessities for mineral filler for Bituminous Paving Mixtures AASHTO M17, and as per AASHTO PP41 (Designing of Stone Matrix Asphalt) and these waste materials might possibly be utilized as mineral fillers in Stone Mastic Asphalt (SMA) Mixtures.

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

Introduction
Modern garbage removal is a major issue in created nations, with a portion of these squanders being scorched in incinerators and the buildup being unloaded on the ground. The utilization of waste and result materials in the development of asphalts enjoys benefits in that it not just diminishes how much waste materials that should be discarded, yet it likewise gets a good deal on development materials when contrasted with new materials. The utilization of these materials can really enhance an issue that was beforehand expensive to discard. Involving modern squanders in black-top substantial asphalt helps the climate, yet it likewise works on a portion of the asphalt's characteristics.

The modern squanders could be utilized as an asphalt primary part. Some are utilized alternative for conventional totals, and others act as part or all of the fastener in a specific blend. Stone Matrix Asphalt (SMA) is a superior sort of hot blend black-top asphalt. One of the part fixings in SMA blends is mineral filler. More than 8-10% of black-top asphalt materials (by weight of total) comprise of mineral fillers in SMA blends.

Literature Review
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).

Existing hot mix asphalt design and analysis techniques are frequently ineffective for mixtures containing waste elements; as a result, procedures must be devised to ensure that they are routinely used successfully (Terrel *et al.*, 1994). Fibers are added as reinforcement in bituminous mixtures. Reinforcement consists of incorporating certain materials with some desired properties within other material which lack those properties (Maurer and Gerald, 1989). Fundamentally, the principal functions of fibers as reinforcing materials are to provide additional tensile strength in the resulting composite and to increase strain energy absorption of the bituminous mixtures (Mahrez *et al.*, 2005).

Objective

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. Mineral fillers, asphalt, fibers, and a tiny amount of fine aggregate particles mix to form a binder-rich mastic that fills the vacuum areas between the coarse aggregate skeleton. Mineral filler specifications are straightforward. As a result, a wide range of materials have been employed as mineral fillers in SMA, including varied mineralogy rock dust products, 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 or slag dust.

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.

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.

Fig 1: Typical ash colors.

Limestone dust (LSD)

Limestone is a sedimentary rock composed largely of the mineral calcite (calcium carbonate: $CaCO3$) 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.

Fig 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

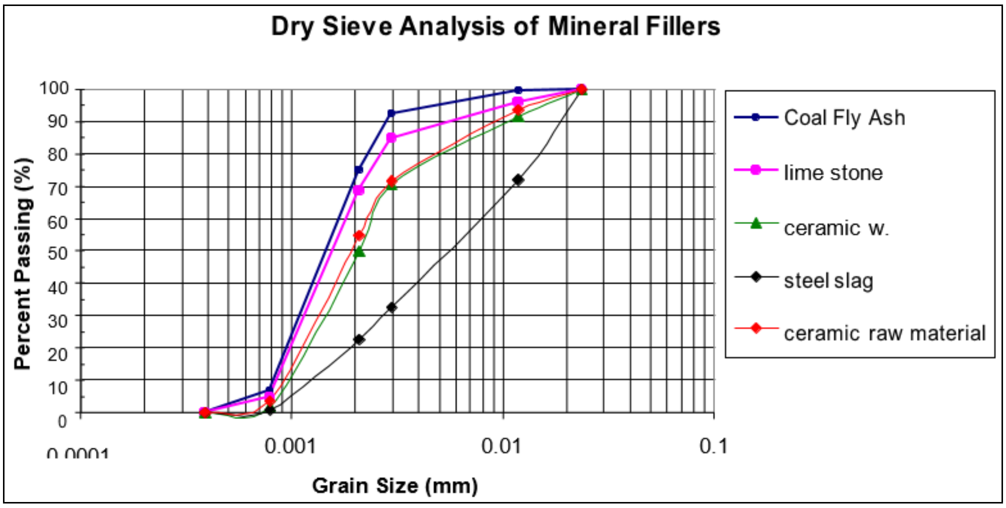


Fig 3: Dry sieve analyses of industrial wastes.

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)

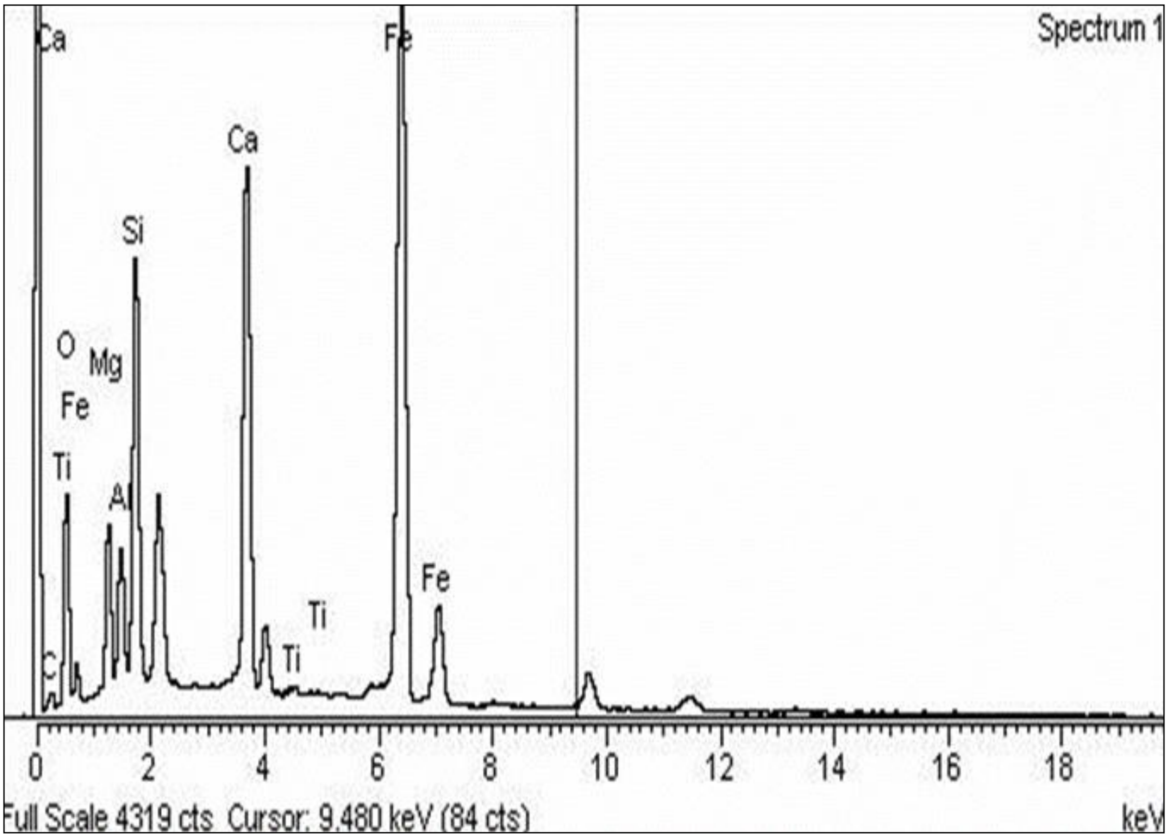


Fig 4: Chemical Composition of Coal Fly Ash.

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. 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.

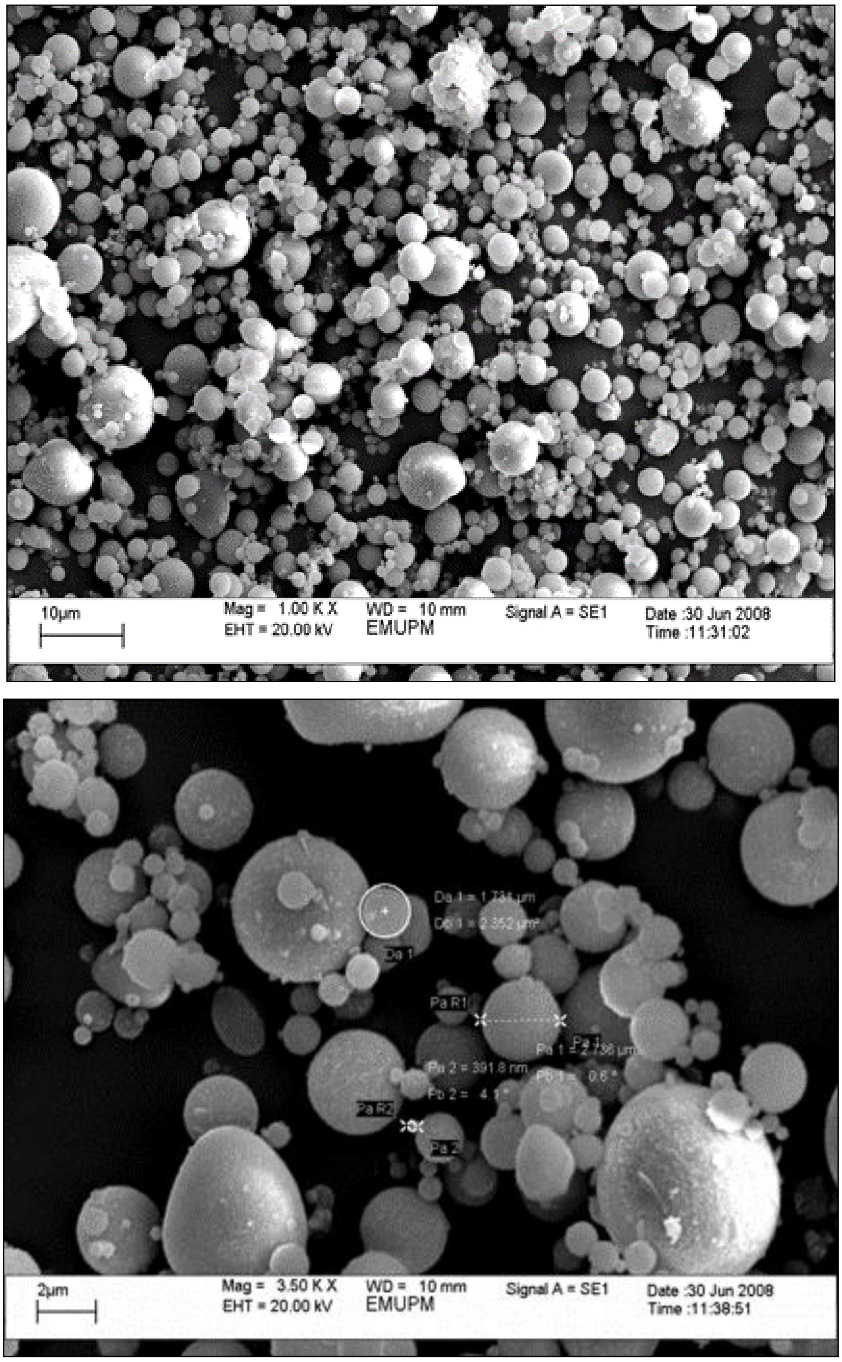


Fig 5: Fly ash particles at 1,000 x and at 3,500 x magnification.

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

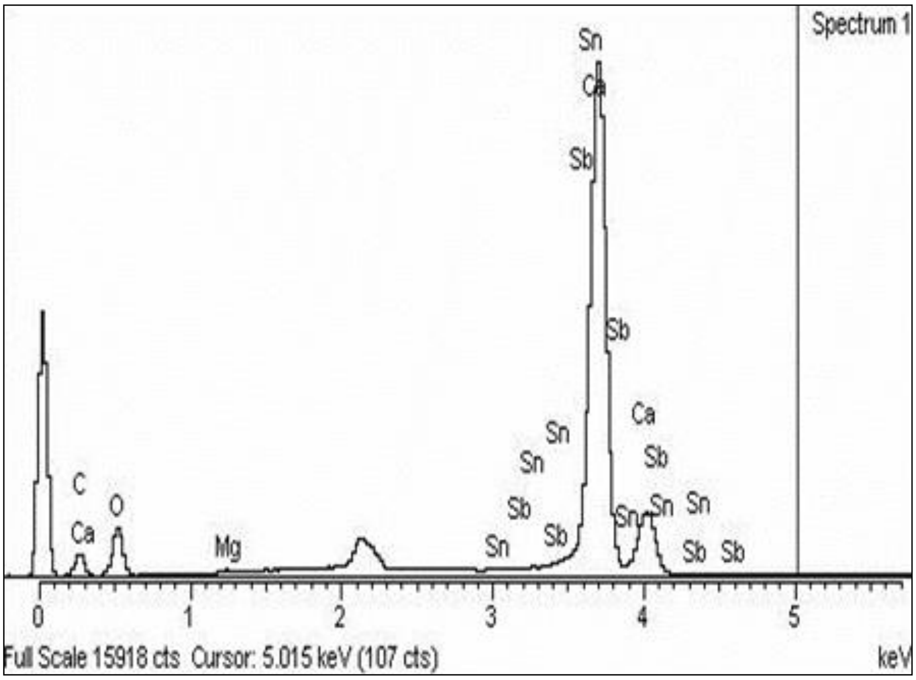
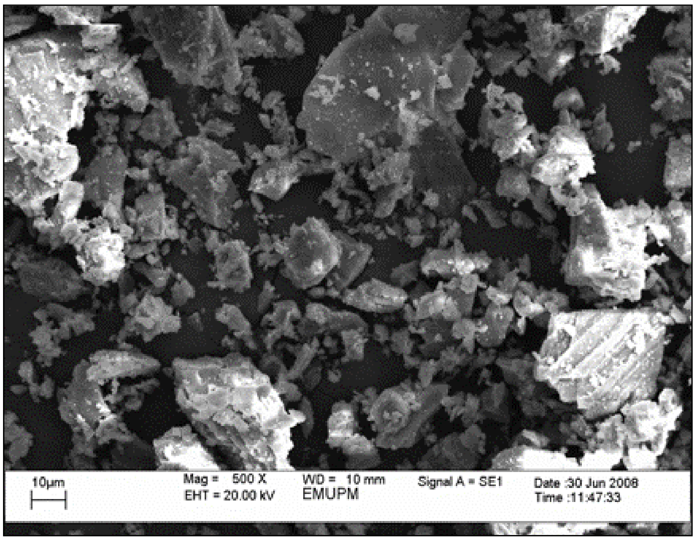


Fig 6: Chemical composition of limestone dust.

b. Physical Properties

Size and Shape



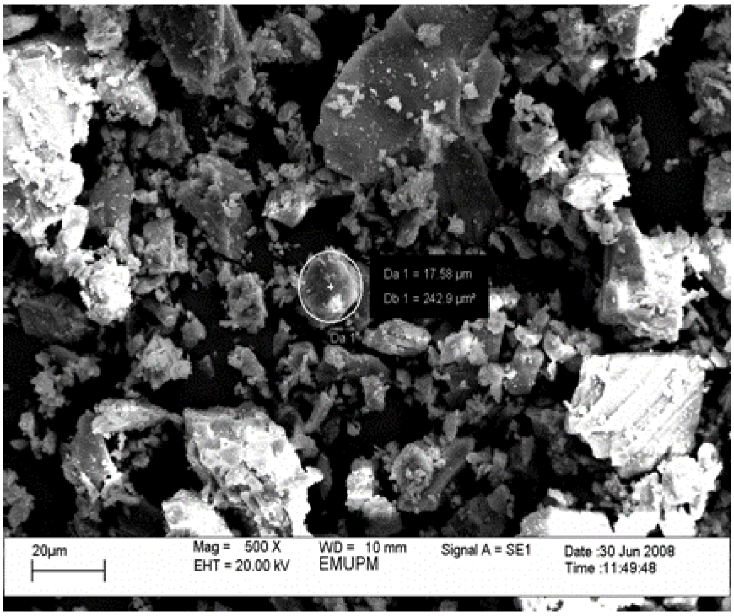


Fig 7: Grain size and particle shape of limestone dust at 500 x magnification.

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	-

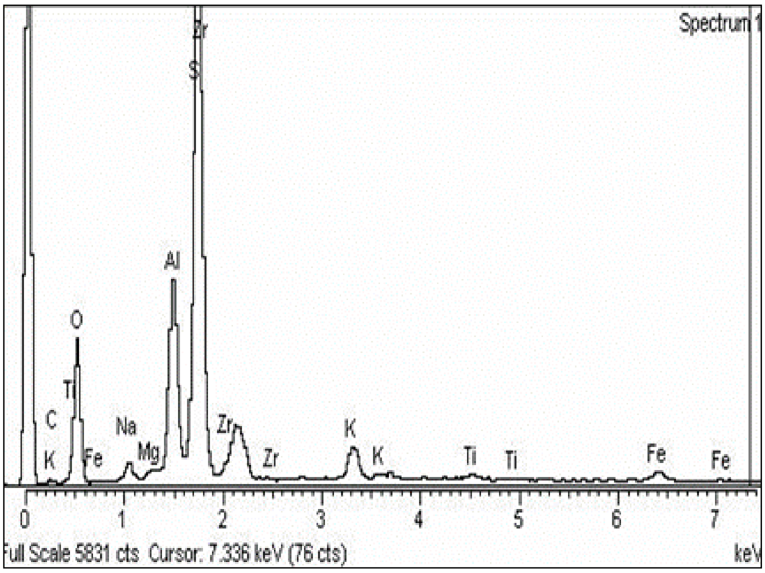


Fig 8: Chemical composition of ceramic waste.

b. Physical properties

Size and shape

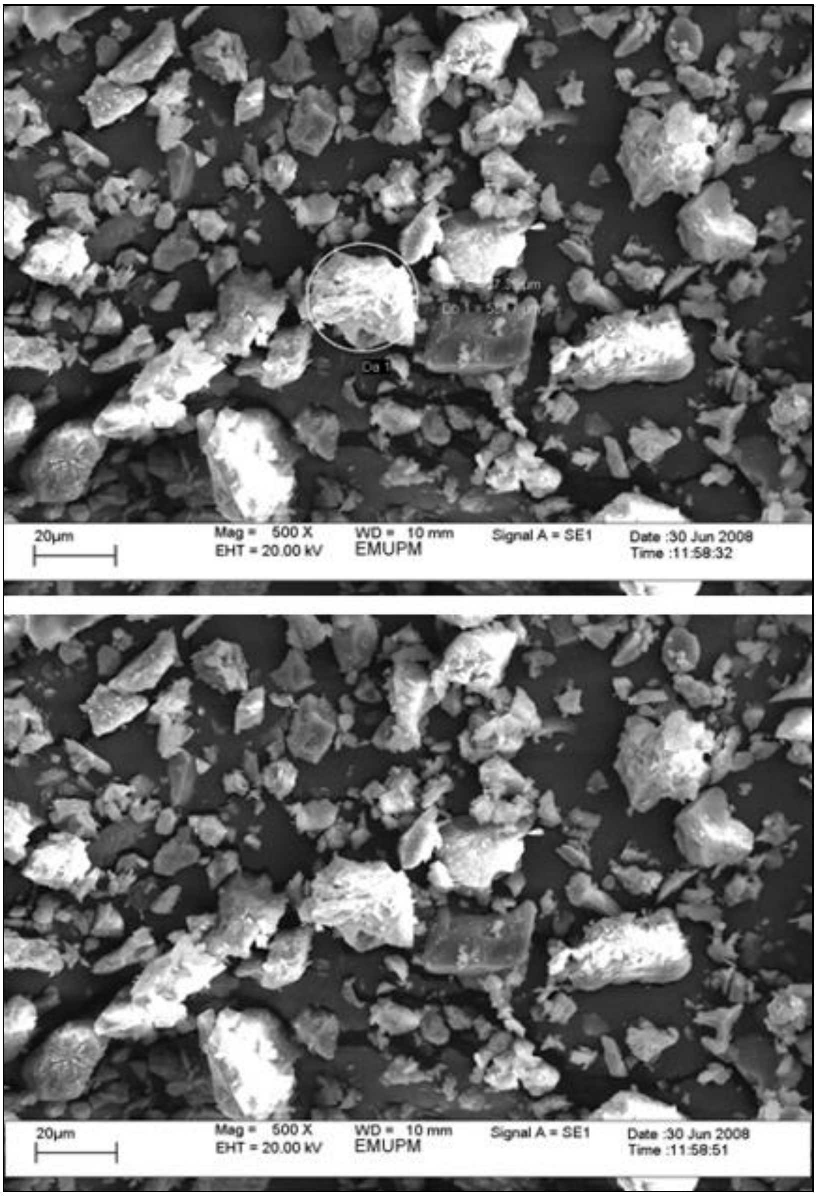


Fig 9: Grain size and particle shape of ceramic waste at 500x magnification.

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	-	

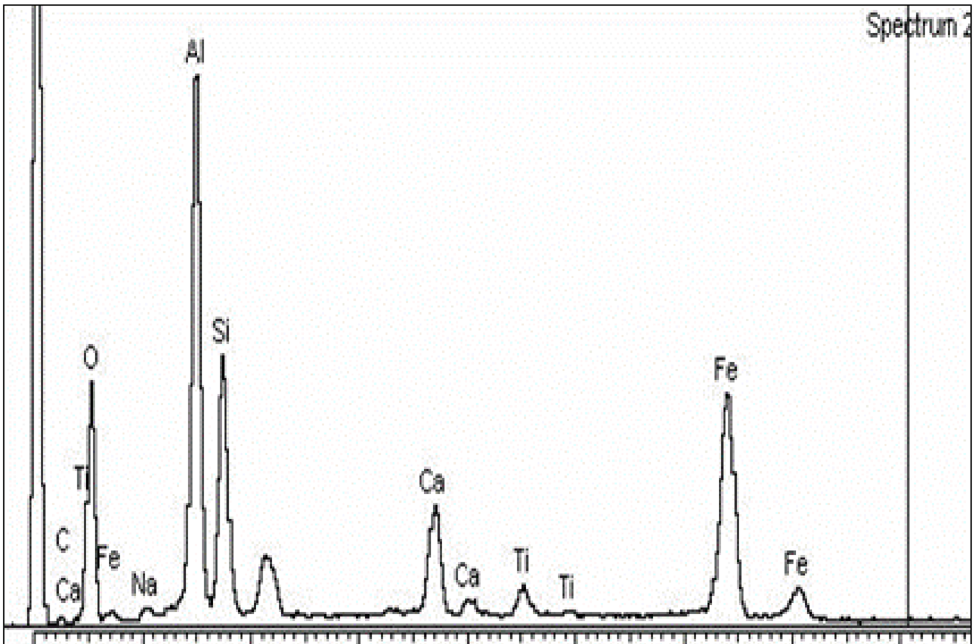


Fig 10: Chemical composition of steel slag.

b. Physical properties

Size and shape

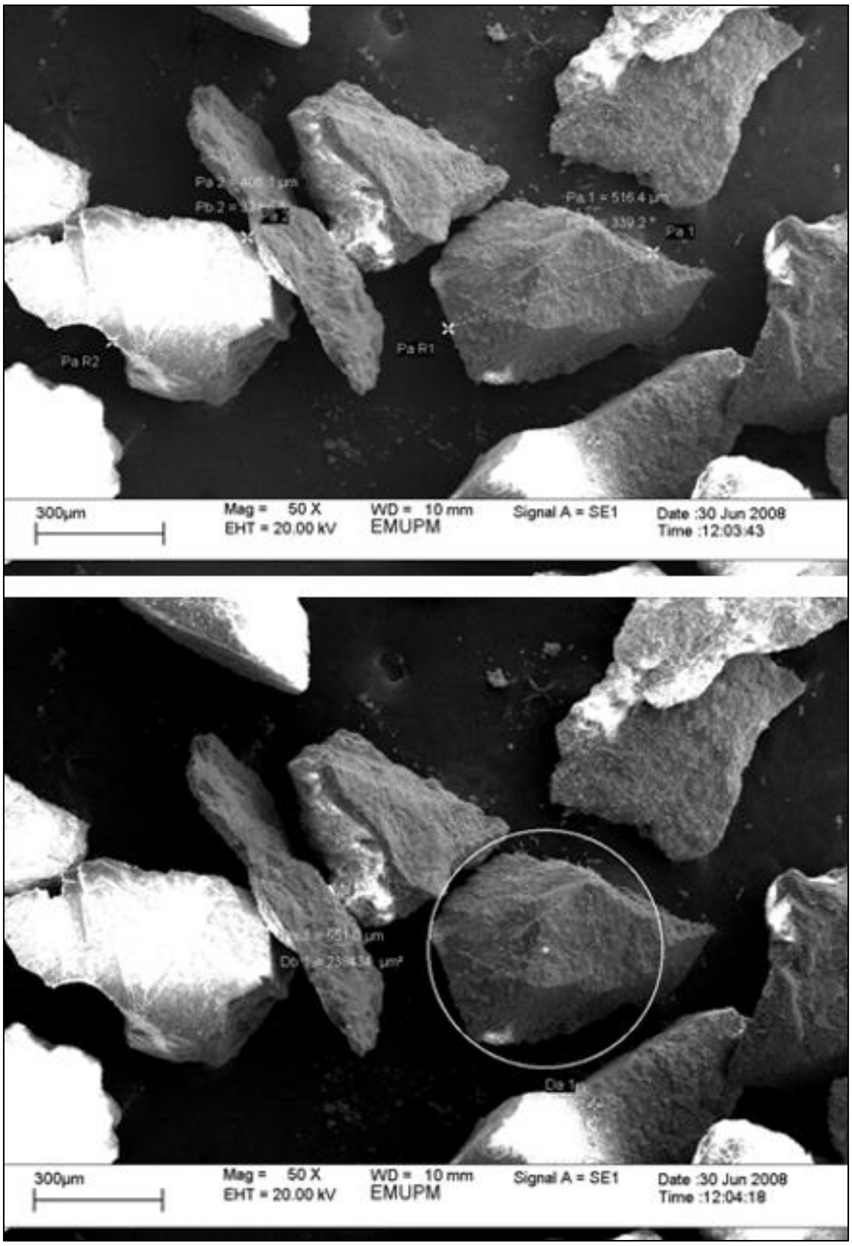


Fig 11: Grain size and particle shape of steel slag at 50x magnification.

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 Na2 O	1.15	1.5% Maximum
Sulfur Trioxide, S O3	-	4% Minimum ASTM C114
Feldspar, Potassium K	1.52	-

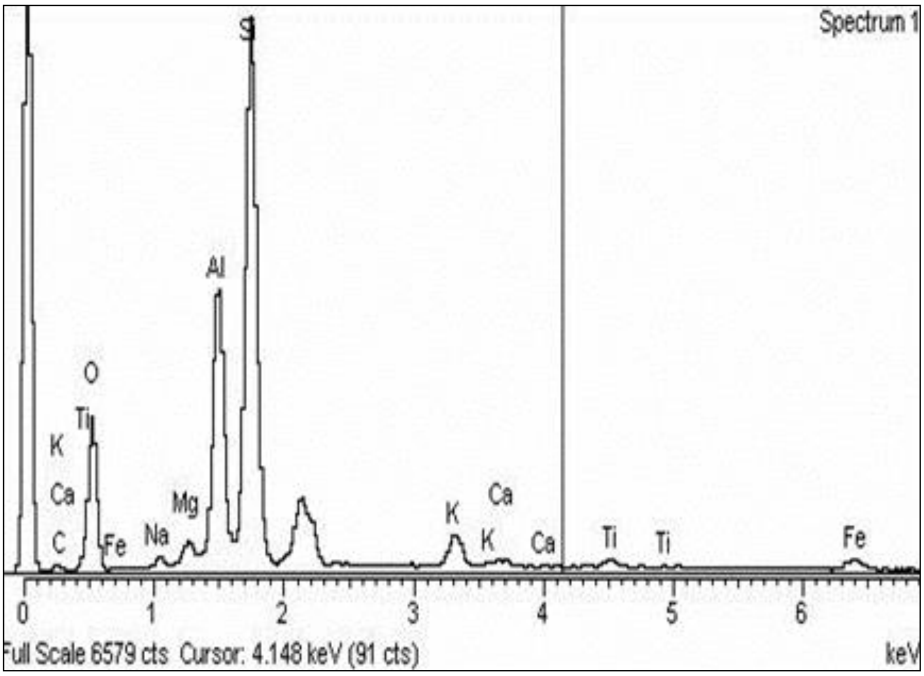
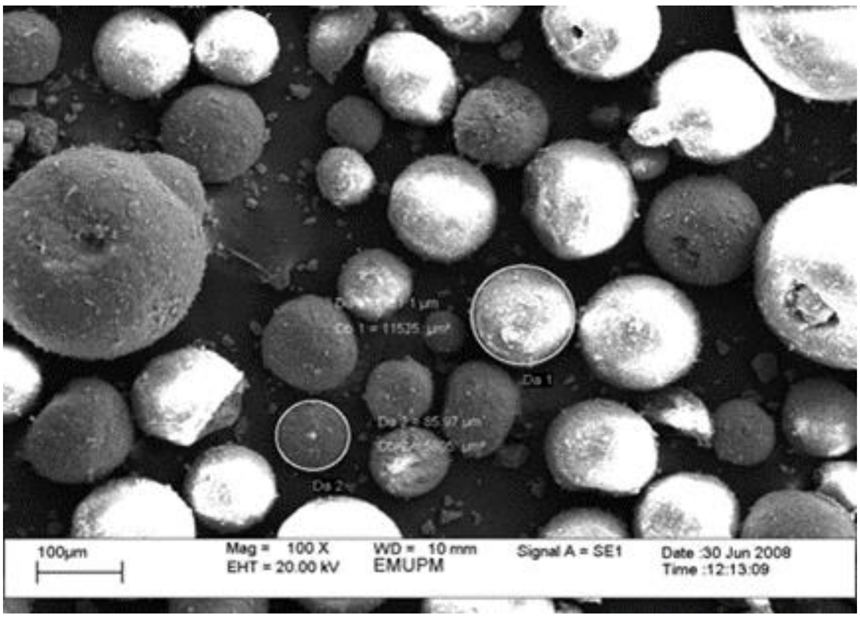


Fig 12: Chemical composition of rejected ceramic raw material.

b. Physical composition
Size and shape



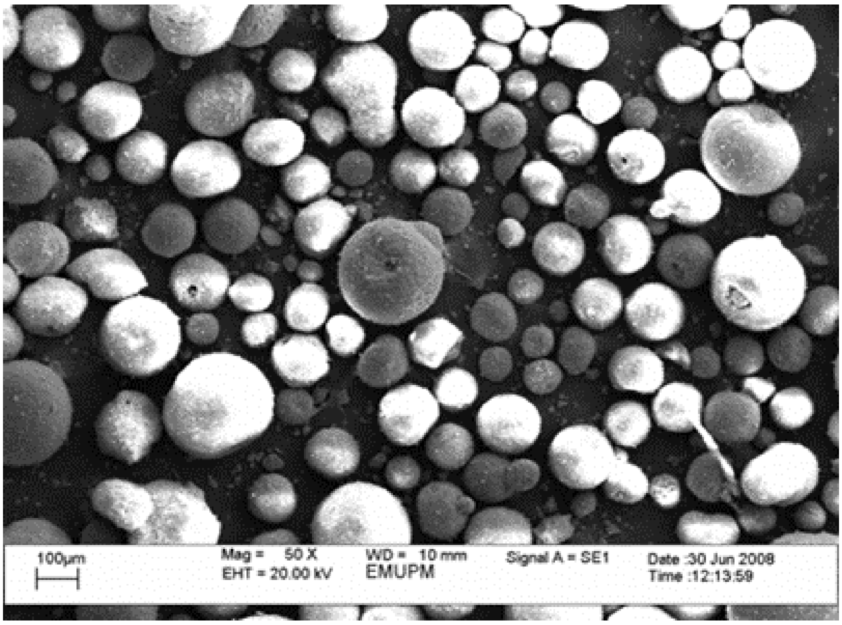


Fig 13: Grain size and particle shape of rejected ceramic raw material at 100x and 50x magnification.

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 review, beginning examination was made on the substance and actual properties to decide the appropriateness of the Malaysian neighborhood modern squanders and side-effects for use as mineral filler for SMA blends. The estimations were performed including degree, dampness content, explicit gravity, methylene blue, dissolvability, grain size, molecule shape, pH esteem, percent fineness, and substance organization. In view of the discoveries of the underlying outcomes, the accompanying principal ends can be attracted by the outcomes acquired:

- Lab tests demonstrate great potential for nearby modern squanders and can be reasonable mineral fillers for stone framework black-top and ensured to meet the necessity of SMA Mixtures;
- The degree adjusted to the degree range determined in AASHTO M17 determination necessities for mineral filler use in black-top clearing blends;
- The mineral organization showed that the Sum of Si O2, Al2 O3, Fe were over the base prerequisite of ASTM C618, Class N, (Natural Pozzolan);
- The huge sum use of modern squanders and results affirmed that it tends to be utilized as likely materials in street development for saving regular assets.
- Be that as it may, not every modern waste and results are something similar and may perform distinctively in research facility tests and field conditions. A few untimely disappointments of SMA asphalts have been credited to mineral fillers while others have performed sufficiently. The accessible calcium oxide content is accepted to be a basic element for whether the modern squanders are reasonable for use as mineral fillers.

From the above results there is a high opportunities for modern squanders and side-effects to be utilized as fillers in black-top cement, and there ought to be further examinations by leading field tests for use of those losses in black-top cement.

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