Report for
ZMM®
Canada Minerals Corp.

Zeopolymer Development using ZMM® Zeolite Basalt Phase 1 Report

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Submitted by:

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Building Knowledge. Delivering Results.

ABSTRACT

ZMM® is a clean technology developer whose mission is to create and deliver innovative, sustainable zeolite basalt solutions. ZMM® has created unique, beneficial, and innovative natural zeolite basalt products and solutions. ZMM® approached CTLGroup to investigate the possibility of developing a geopolymer composition using their natural zeolite basalt material. CTLGroup proposed a multiphase research and development approach to perform the investigation. This report summarizes the findings of Phase I literature review conducted on the testing that has been performed previously on ZMM® zeolite basalt. Based on the review of the available reports, it can be concluded that it may be possible to develop a geopolymer using ZMM's zeolite basalt. The report provides recommendations for Phase II, which is the preliminary work of geopolymer laboratory evaluation for a Zeopolymer.

1. BACKGROUND

ZMM® Canada Minerals Corp. (hereafter ZMM®), founded by LuVerne (Verne) E.W. Hogg, based in Peachland, British Columbia, Canada, is specializing in the commercialization of zeolite basalt. ZMM® conducts innovative, applied research, development, and commercialization of zeolite basalt products in collaboration with industry, universities, and government agencies while generating proprietary intellectual properties focusing on creating sustainable and economic climate change solutions.

ZMM® has developed two high-purity innovative zeolite basalt solutions for sustainable environmental applications while reducing greenhouse gas emissions. The high purity zeolite basalt solution developed by ZMM® is Canada's first commercial-grade discovery of high purity, natural crystalline zeolite basalt. ZMM's founder, Mr. Hogg, has been a global expert specializing in applied research and development of Zeolite basalt minerals, products, and their applications for over 30 years.

Figure 1: Volcanic vesicular flow rock

Zeolites are crystalline hydrated alumino-silicates composed of silicon and aluminum tetrahedra (SiO_4 and AlO_4) and linked by an oxygen atom. Zeolites are present naturally and can also be produced synthetically. Natural zeolites occur as a result of two specific historical geological events: volcanic ashfall, which created sedimentary zeolite. Some volcanic vesicular flow rock occurrences host the second zeolite basalt. ZMM® zeolite basalt is found to present naturally due to Basaltic vesicular flow rocks. All zeolite basalt produced from the ore bodies is utilized resulting in a no-waste operation.

ZMM® has developed multiple market-ready products. The industrial product developed by ZMM® functions as Supplementary Cementitious Materials (SCM) and is used in new zeolite basalt environmental applications.

ZMM$^{®}$ has developed multiple sustainable engineered systems like **Cold Zone Composting (CZC)** for remediation of petroleum waste year-round. The Cold Zone Composting (CZC) system designed by ZMM$^{®}$ is for cold zone temperatures. ZMM's zeolite/basalt is used as an SCM replacement to encapsulate radioactive and hazardous wastes utilizing ZMM's **Isolate, Stabilize and Solidify (ISS) system**. ZMM$^{®}$ is currently developing **Vacuum Insulation Panels (VIP)** and low-cost Thermal Energy Storage (TES) systems. The vacuum insulation panels are created using ZMM$^{®}$ zeolite-fiber composite core. ZMM$^{®}$ is utilizing its high purity crystalline (HPC) zeolite in developing its next-generation low-cost, high-performance residential **Thermal Energy Storage (TES)** system. Using natural zeolite materials in TES will substantially reduce energy costs and GHG emissions.

ZMM$^{®}$ approached CTLGroup to identify the possibility of activating their natural zeolite basalt with alkalis and developing a Zeopolymer. Geopolymer concrete uses no Portland cement at all, and therefore the "cement" or binding element of the concrete is almost carbon neutral. Typically, a Geopolymer concrete is made by mixing the sand and aggregate with alumino-silicate materials like fly ash or slag and activating it with an alkali such as sodium hydroxide.

Geopolymers are inorganic materials produced by synthesizing silica-alumina gels in an alkaline environment. Their microstructure consists of chains or networks of inorganic molecules linked by covalent bonds. These molecules are composed of one silicon or aluminum atom connected by four oxygen atoms forming tetrahedrons, combined in a three-dimensional network sharing one common oxygen atom like a zeolite. The primary raw material to produce geopolymers is an alumino-silicate material. The primary raw material can be of natural origins such as kaolin zeolite basalt or natural pozzolans that may also be a thermally treated material such as metakaolin, fly ash, granulated blast furnace slag, and basalt which is an alternative calcined shale, and other industrial residues. The alumino-silicate material must be activated by a second raw material called the activator. Common activators are sodium and potassium hydroxide, sodium, and potassium silicate solutions (water glass), sodium and potassium citrate, and sodium carbonate. Due to their chemical composition, natural zeolite basalt can be used as a raw material to produce geopolymers.

The empirical chemical formula of geopolymers is as follows:

$$\mathbf{Mn\{(SiO_2)zAlO_2\}n\ wH_2O}$$

Where M is a cation, n is the degree of polycondensation, w is the number of water molecules, and z equals 1, 2, or 3. The structure of the primary binding matrix in geopolymer is comparable to synthetic or natural crystalline zeolite basalt. It has been around since the late 1970s but only recently attracting commercial interest globally.

The kinetics of alkali activation is highly dependent on the chemical composition of the binder material and the activator concentration. The geo-polymerization process depends on many factors including chemical and mineralogical compositions, particle size distribution and specific surface area of the raw material, Si/Al molar ratio, the water content, the alkali content, and the curing conditions. The unique properties of geopolymer, such as fire and chemical resistance, low thermal conductivity, and low shrinkage, make it suitable for many applications. Geopolymer concrete will become more widely used as geopolymer products become available. The growing importance of sustainability and carbon-neutrality to address GHG emissions zeolite basalt a desirable option.

2. PHASE I REVIEW OF ZMM® ZEOLITE BASALT

ZMM® zeolites are naturally occurring alumino-silicate materials with unique properties. They have a remarkable molecular surface area of approximately 600 to 800 m^2/gram. ZMM® zeolite minerals are crystalline minerals with defined molecular structures.

Figure 2: ZMM ® High Purity Zeolite Crystals

The following work has been completed in Phase I to evaluate the potential of ZMM® natural zeolite basalt in developing a geopolymer:

1. Review of documents supplied by ZMM® Canada Minerals Corp.
2. Review old test reports generated by ZMM® or another laboratory/consulting group.
3. Limited literature and patent searches for related materials.
4. Visual inspection of the Zeolite/Basalt materials supplied by ZMM®.
5. Determination of what consulting and testing will be required in Phase II.

The following advantages of ZMM® zeolite will guide future technology advancement.

- Logistical – ZMM® has identified two high purity zeolite/ basalt orebodies *(TransCanada and Juniper)* in proximity to Kamloops, British Columbia, a central transportation hub in western Canada on the TransCanada Highway and Canadian National and Canadian Pacific rail yards.
- Low-cost surface quarrying – The cost of quarrying ZMM's zeolite/basalt is low compared to the traditional cost of quarrying any other natural zeolite. The quarrying process has considered conventional processing with minimal environmental footprint and produces nowaste.

Visual Inspection

ZMM® provided fifteen (15) samples for visual inspection with eight (8) different particle sizes from TransCanada and seven (7) different particle sizes from Juniper. Figures 3 through 16 provide visual illustration of ZMM® materials with various particle sizes. The ability of ZMM® to make zeolite basalt under different particle sizes can be leveraged to control the flow behavior of the concrete when made with their zeolite/basalt.

Figure 3: Juniper Ore.

Figure 4: Juniper -2+4 Mesh.

Figure 5: Juniper -4+6 Mesh.

Figure 6: Juniper -6+8 Mesh.

Figure 7: Juniper -8+10 Mesh.

Figure 8: Juniper -20+80 Mesh.

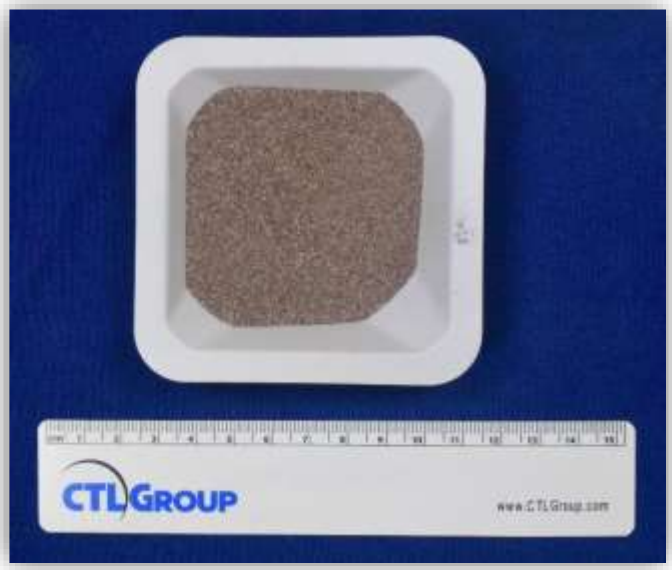

Figure 9: Juniper -20+100 Mesh.


Figure 10: TransCanada Ore.


Figure 11: TransCanada -2+4 Mesh.

Figure 12: TransCanada -4+6 Mesh.

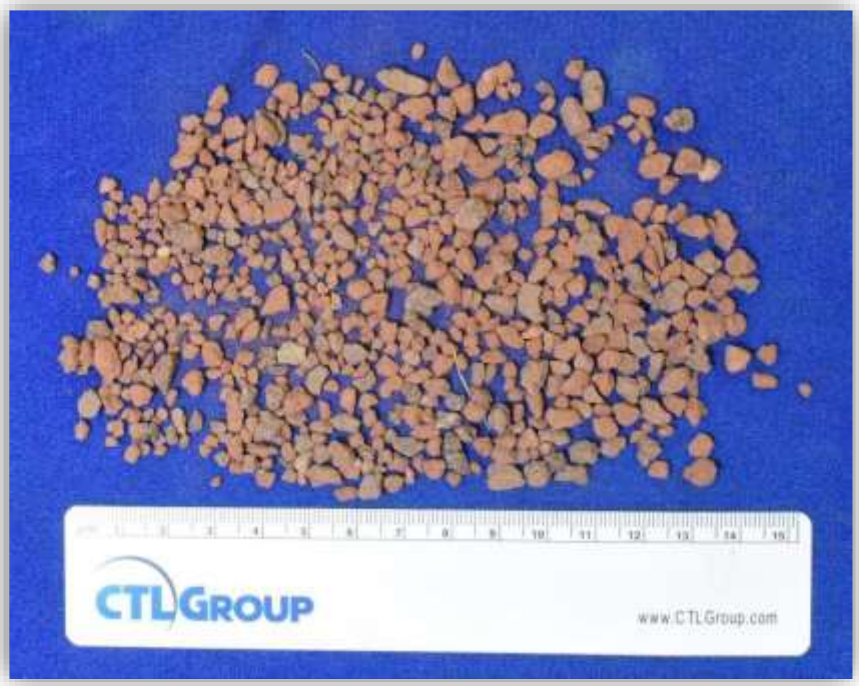

Figure 13: TransCanada -4+8 Mesh.

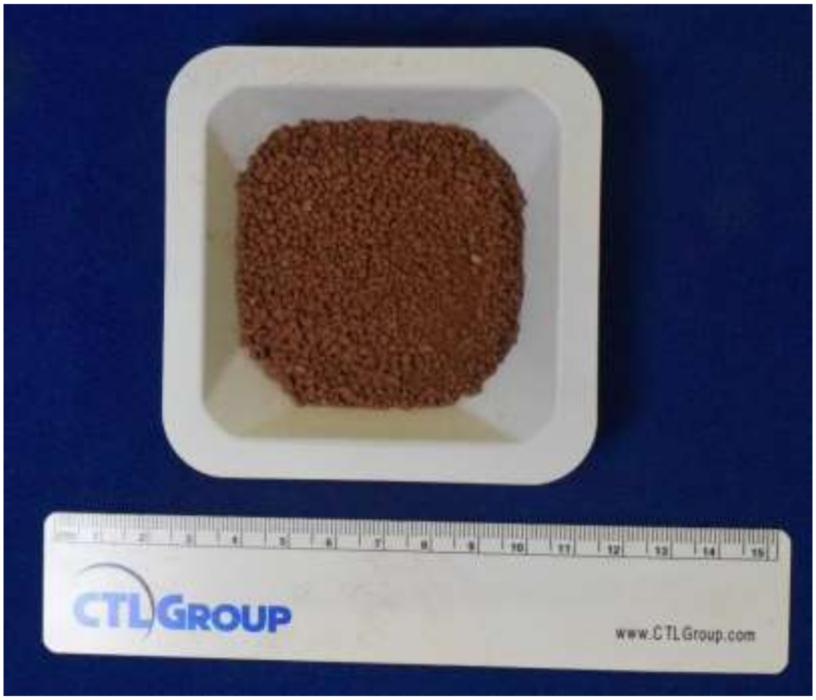

Figure 14: TransCanada -8+10 Mesh

Figure 15: TransCanada -10+20 Mesh

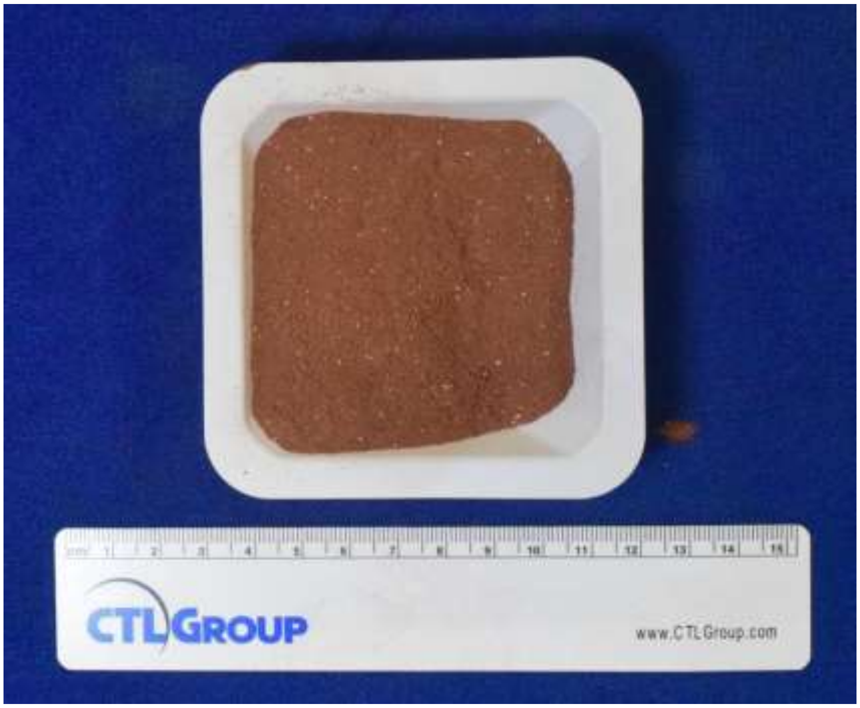

Figure 16: TransCanada -20 Mesh

Figure 16: TransCanada 3 microns

TransCanada samples were red, while the Juniper samples provided were black or brown. It is also possible to use the coarser samples as a filler (coarse or fine aggregate) to make a geopolymer concrete. The particle size analysis for ZMM® zeolite basalt TransCanada Red was performed by Jet Pulverizer Company in Feb 2020. The mean and median particle size of the ZMM® zeolite basalt per the Jet Pulverizer company's reports are as follows:

Sample Number	**Mean (μm)**	**Median (μm)**	**Standard Deviation (μm)**
1	3.79	3.44	2.15
2	4.70	4.36	2.53
3	13.07	6.54	26.35

Chemical Analysis and Physical Testing

SGS Tech Services in Dec 2019 carried out the chemical and physical analysis per ASTM C618[1] testing on ZMM® zeolite basalt. ZMM® zeolite basalt conforms to ASTM C618 as a pozzolanic material per the SGS report. The report is furnished below. According to the report, ZMM® zeolite basalt contained 52.4% SiO_2, followed by Al_2O_3 at 14.5% and Fe_2O_3 at 8.79%. Due to the presence of significant amounts of silica and alumina, ZMM® zeolite basalt is a pozzolan. The physical analysis tests performed on ZMM® zeolite basalt by SGS complies with the ASTM C618-19 and AASHTO M295-19 specifications for Class N pozzolans.

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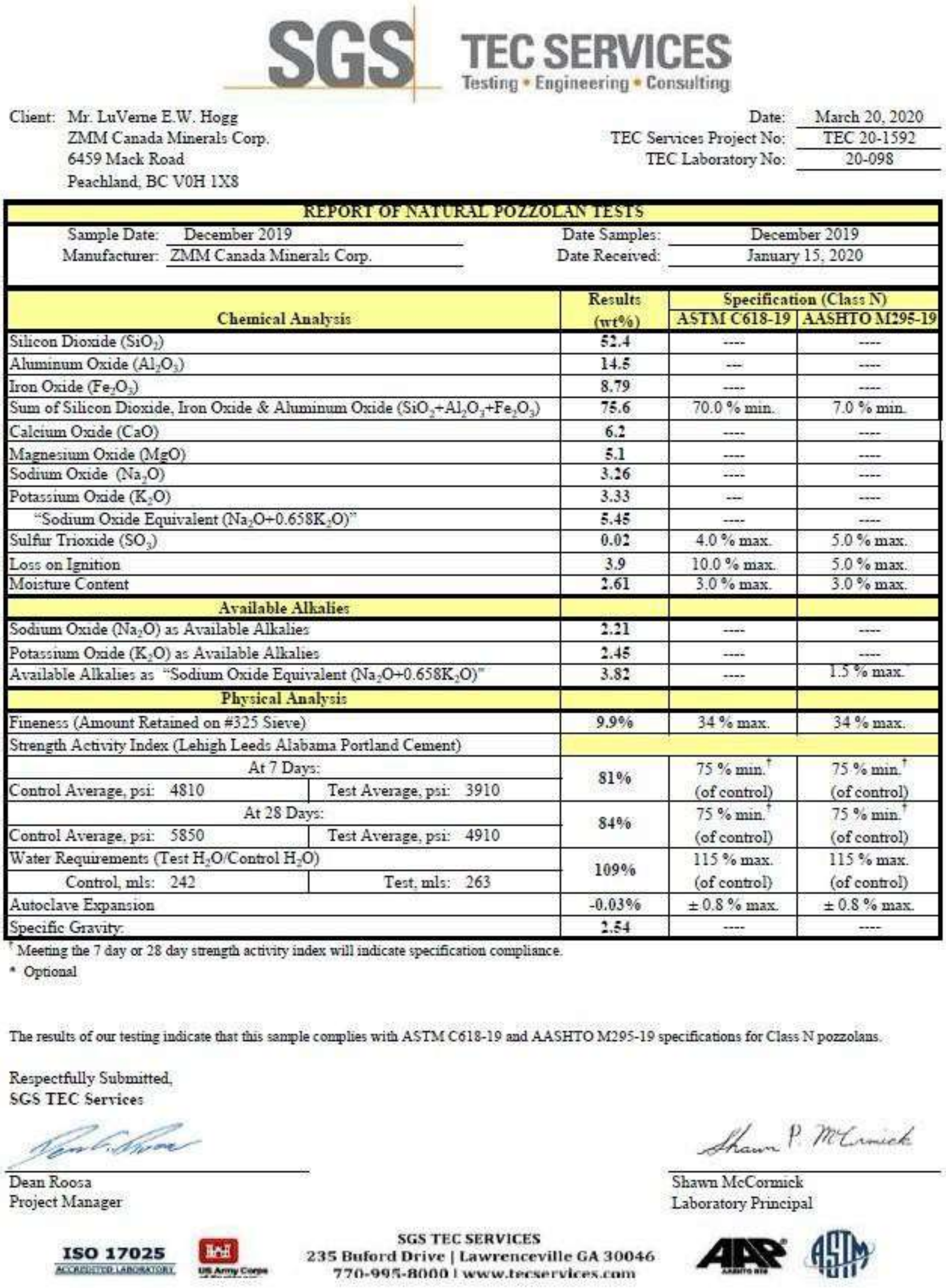
[1] ASTM C618, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*, 2019.



SGS TEC SERVICES
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Date: March 20, 2020
TEC Services Project No: TEC 20-1592
TEC Laboratory No: 20-098

REPORT OF NATURAL POZZOLAN TESTS

Sample Date: December 2019
Manufacturer: ZMM Canada Minerals Corp.
Date Samples: December 2019
Date Received: January 15, 2020

Chemical Analysis	Results (wt%)	Specification (Class N) ASTM C618-19	Specification (Class N) AASHTO M295-19
Silicon Dioxide (SiO_2)	52.4	----	----
Aluminum Oxide (Al_2O_3)	14.5	---	----
Iron Oxide (Fe_2O_3)	8.79	----	----
Sum of Silicon Dioxide, Iron Oxide & Aluminum Oxide (SiO_2+Al_2O_3+Fe_2O_3)	75.6	70.0 % min.	7.0 % min.
Calcium Oxide (CaO)	6.2	----	----
Magnesium Oxide (MgO)	5.1	----	----
Sodium Oxide (Na_2O)	3.26	----	----
Potassium Oxide (K_2O)	3.33	---	----
"Sodium Oxide Equivalent (Na_2O+0.658K_2O)"	5.45	----	----
Sulfur Trioxide (SO_3)	0.02	4.0 % max.	5.0 % max.
Loss on Ignition	3.9	10.0 % max.	5.0 % max.
Moisture Content	2.61	3.0 % max.	3.0 % max.
Available Alkalies			
Sodium Oxide (Na_2O) as Available Alkalies	2.21	----	----
Potassium Oxide (K_2O) as Available Alkalies	2.45	----	----
Available Alkalies as "Sodium Oxide Equivalent (Na_2O+0.658K_2O)"	3.82	----	1.5 % max.[*]
Physical Analysis			
Fineness (Amount Retained on #325 Sieve)	9.9%	34 % max.	34 % max.
Strength Activity Index (Lehigh Leeds Alabama Portland Cement)			
At 7 Days: Control Average, psi: 4810 Test Average, psi: 3910	81%	75 % min.[†] (of control)	75 % min.[†] (of control)
At 28 Days: Control Average, psi: 5850 Test Average, psi: 4910	84%	75 % min.[†] (of control)	75 % min.[†] (of control)
Water Requirements (Test H_2O/Control H_2O) Control, mls: 242 Test, mls: 263	109%	115 % max. (of control)	115 % max. (of control)
Autoclave Expansion	-0.03%	± 0.8 % max.	± 0.8 % max.
Specific Gravity:	2.54	----	----

[†] Meeting the 7 day or 28 day strength activity index will indicate specification compliance.

[*] Optional

The results of our testing indicate that this sample complies with ASTM C618-19 and AASHTO M295-19 specifications for Class N pozzolans.

Respectfully Submitted,
SGS TEC Services

Dean Roosa
Project Manager

Shawn P. McCormick

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Laboratory Principal

ISO 17025 ACCREDITED LABORATORY
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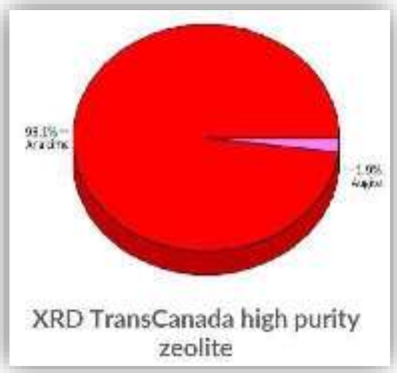
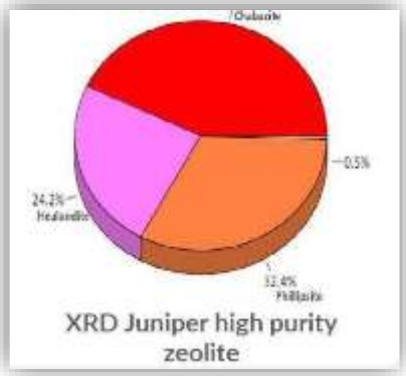
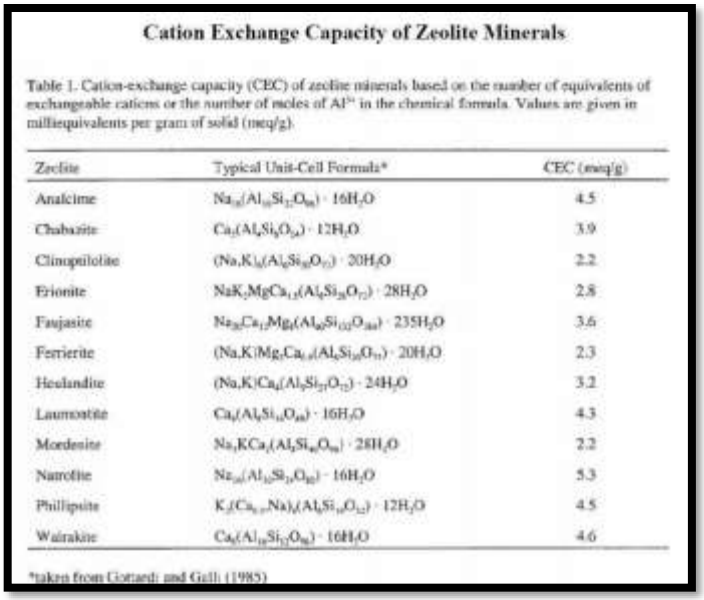
X-ray Diffraction

According to the safety data sheet developed by ZMM®, their zeolite material is found to contain about 70 wt.% natural zeolites and between 3 to 7 wt.% of water. ZMM® TransCanada and Juniper natural zeolites contain Analcime, Chabazite, Heulandite (Clinoptilolite), and Phillipsite (See figure below). Analcime is dominant in TransCanada ZMM® zeolite, while Chabazite, Heulandite (Clinoptilolite), and Phillipsite were all present in Juniper ore. Clinoptilolite is typically found to be prevalent in other natural zeolites. This indicates ZMM® zeolite is very distinct from the conventional zeolite material present in other parts of the world.





The cation exchange capacities of Analcime and Chabazite are 4.5 and 3.9 meq/g, respectively. This is given in the table below as a figure. This is compared to be significantly higher than the cation exchange capacity of Clinoptilolite.



Cation Exchange Capacity of Zeolite Minerals

Table 1. Cation-exchange capacity (CEC) of zeolite minerals based on the number of equivalents of exchangeable cations or the number of moles of Al^{3+} in the chemical formula. Values are given in milliequivalents per gram of solid (meq/g).

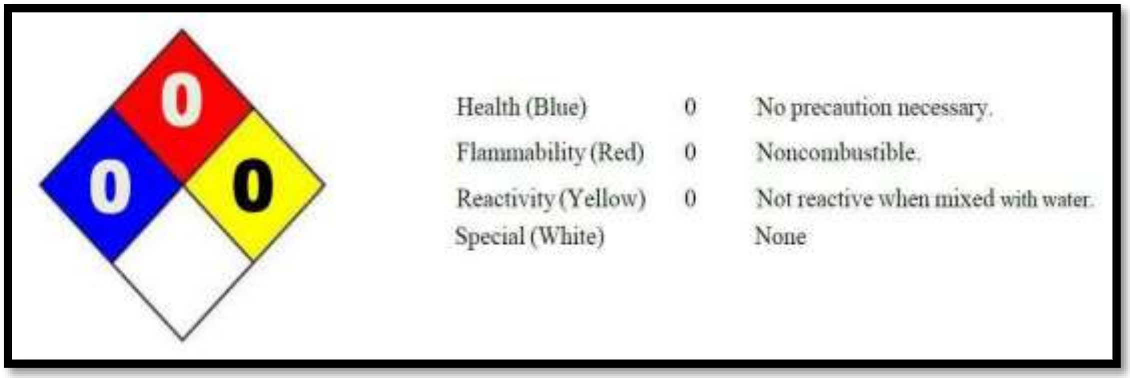
Zeolite	Typical Unit-Cell Formula*	CEC (meq/g)
Analcime	$Na_{16}(Al_{16}Si_{32}O_{96}) \cdot 16H_2O$	4.5
Chabazite	$Ca_2(Al_4Si_8O_{24}) \cdot 12H_2O$	3.9
Clinoptilolite	$(Na,K)_6(Al_6Si_{30}O_{72}) \cdot 20H_2O$	2.2
Erionite	$NaK_2MgCa_{1.5}(Al_8Si_{28}O_{72}) \cdot 28H_2O$	2.8
Faujasite	$Na_{20}Ca_{12}Mg_8(Al_{60}Si_{132}O_{384}) \cdot 235H_2O$	3.6
Ferrierite	$(Na,K)Mg_2Ca_{0.5}(Al_6Si_{30}O_{72}) \cdot 20H_2O$	2.3
Heulandite	$(Na,K)Ca_4(Al_9Si_{27}O_{72}) \cdot 24H_2O$	3.2
Laumontite	$Ca_4(Al_8Si_{16}O_{48}) \cdot 16H_2O$	4.3
Mordenite	$Na_3KCa_2(Al_8Si_{40}O_{96}) \cdot 28H_2O$	2.2
Natrolite	$Na_{16}(Al_{16}Si_{24}O_{80}) \cdot 16H_2O$	5.3
Phillipsite	$K_2(Ca_{0.5},Na)_4(Al_6Si_{10}O_{32}) \cdot 12H_2O$	4.5
Wairakite	$Ca_8(Al_{16}Si_{32}O_{96}) \cdot 16H_2O$	4.6

*taken from Gottardi and Galli (1985)

The geopolymerization process is an exothermic polycondensation reaction involving alkali activation by a cation in solution. The high cation exchange capacity of ZMM® zeolite can play a significant role in developing a geopolymer using ZMM® zeolite as a pure binder.

<u>The safety aspect of ZMM® Zeolite Basalt</u>

According to GHS and CLP regulations, ZMM® zeolite basalt is not considered hazardous. The classification is according to the latest editions of the EU lists and extended by the company safety data sheet.



Health (Blue)	0	No precaution necessary.
Flammability (Red)	0	Noncombustible.
Reactivity (Yellow)	0	Not reactive when mixed with water.
Special (White)		None

3. CONCLUSIONS

Based on the findings of Phase I, the following conclusions can be made regarding the ZMM® zeolite basalt:

1. ZMM's natural zeolite basalt is pozzolanic and has the potential to be used as a supplement to cement in concrete.
2. ZMM's natural zeolite basalt is an alumino-silicate material with a high Si/Al ratio (>3). The summation of Silicon dioxide, Aluminum Oxide, and Iron Oxide (SiO_2 + Al_2O_3 + Fe_2O_3) is more than 70%, similar to Class-F fly ash. This indicates the potential for using this material as SCM.
3. It is possible to develop a Zeopolymer by activating ZMM's natural alumino-silicate zeolite basalt material using suitable alkalis. Activator type and concentration, and curing conditions are considered crucial factors influencing a geopolymer development. The factors mentioned above will affect the chemical and mineral structure of the Zeopolymer.

4. RECOMMENDATIONS

Based on the conclusions made from Phase I of this project, it can be concluded that it is possible to develop a Zeopolymer by activating ZMM’s natural aluminosilicate zeolite basalt material using suitable alkalis. The following work is proposed for Phase II to further investigate the suitability of ZMM’s materials in concrete production and development of a Zeopolymer.

Activator Selection

Based on the review of geopolymer formation using natural zeolite basalt, the activator type, activator concentration, and curing conditions are crucial factors to consider when developing the geopolymer using ZMM® zeolite basalt. The next step in Phase II involves selecting suitable alkalis that can be utilized to develop a Zeopolymer with ZMM® zeolite basalt. This step consists of selecting of minimum 3 to 4 alkalis based on prior work on zeolite basalt mixing the alkali solution with ZMM® zeolite basalt and testing for the setting time using recommended ASTM test procedures. During this step of activator selection, a mixing approach should also be developed.

Activator Concentration

The alumino-silicate materials are typically activated using an alkaline solution that will allow them to harden and develop sufficient strength. Once a suitable activator is selected, the next step in Phase II is to identify the activator concentration that will allow growing good power depending on the product's application. Typically, a 3000 PSI compressive strength is considered a reasonable strength development. For pozzolanic materials, strength development happens even after 28 days, at 56 days and 90 days.

Curing Condition

Based on the literature review, it has been determined that strength development in geopolymer happens with higher temperatures, especially for materials with higher silica content (>70 wt.%). Thus, curing condition becomes an essential factor to be evaluated in this Phase. All curing conditions like air, moisture, heat (different temperatures) will be assessed, and analytical work performed. Analytical evaluation using X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Particle Size Analysis (PSA), Thermo-gravimetric Analysis (TGA), X-ray Fluorescence (XRF) will be performed as required.

By performing the proposed Phase II work, it will be possible to validate the claims made in this report. CTLGroup will provide a proposal for Phase II to ZMM®. Sustainability and carbon-neutrality make the production of Zeopolymer from natural zeolite basalt a desirable option.

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