

# POTENTIAL USE OF CRUSHED GLASS AS A REPLACEMENT FOR NATURAL AGGREGATE

A Presentation to Manitoba Community Recycling  
and Waste Reduction – October 17, 2024

Ken Skaftfeld, M.Sc., P.Eng. FEIC

TREK Geotechnical



# OUTLINE

- Introduction
- Previous Studies
- Material Description
- Physical, Mechanical, and Chemical Properties
- Comparison With Natural Aggregate
- Potential Uses
  - Construction Aggregate
  - Drainage Media
- Barriers to Using Crushed Glass



# INTRODUCTION

- Of the ~ 10,000,000 Metric Tons (MT) of glass that entered the (1998) waste stream in the US, ~ 7,000,000 MT went into landfills (USEPA 2000).
- In 2022, Manitoba recovered ~ 12,000 MT of glass through their recycling programs (Multi-Material Stewardship Manitoba)
- Recycling glass is theoretically sustainable since clean glass can be re-melted to produce new glass products (Ackerman, et al 2018).  
However, none of the glass recovered in Manitoba is used this way.



*Manitoba no longer has a major bottling plant to recycle glass and without a close end-market, the cost and emissions to transport glass to be recycled into new containers are too great (MMSM 2024).*

A 2018 US survey showed that 43% of glass was re-melted in bottle manufacturing but 30% ended up at the landfill (Ackerman et al 2018).

The survey also identified other uses of collected glass however, most of the survey participants were from densely populated US states where bottle manufacturing takes place.

USES	PROPORTION (%)	GLASS PURITY	MARKET PRICE RANGE (\$/MT) (negative)
Bottle Plant	43	99.8	30 to 100
Alternate landfill cover	21	80	(35 to 75)
Fiberglass insulation	16	99	0 to 50
Road base	15	95	0 to (85)
Sandblast (medium)	11	99	0 to 50
Landfill with other garbage	9	NA	(35 to 75)

Note: Price and purity data from conversations with staff at Alberta Recycling Council, Cascades and:  
<https://www.recyclingproductnews.com/article/27088/breaking-down-the-factors-behind-scrap-glass-prices>

# A FEW THINGS TO FIRST CONSIDER

- Glass jars and bottles are 100% recyclable.
- Glass can be recycled indefinitely without degrading its quality.
- Recycled glass provides ~ 95% of the material needed to produce new glass products.
- In removing glass as early as possible in the recycling stream, it gets mixed with organics, ceramics, shredded paper, and other small objects less than 50 mm and often will be 20-30% contaminated.
- Contamination levels are a key factor affecting the market price of recycled (or reclaimed) glass.

## SO, WHAT HAPPENS IN MANITOBA?

Glass is collected, sorted, crushed, and then goes to the Brady Road Landfill where it is used to build and repair haul roads, replacing sand and gravel - it is thus *reused*.

## ARE THERE OTHER WAYS TO REUSE OR RECYCLE GLASS?

It can be complicated, but the short answer is yes. This presentation will discuss reusing glass as a potential substitute for natural aggregates in engineering applications.



**Reusing** involves taking items that might otherwise be considered waste and finding new applications for them, without changing the original form or intent.

**Recycling** is the process of taking waste materials and converting them back into raw materials to be used in creating new products.

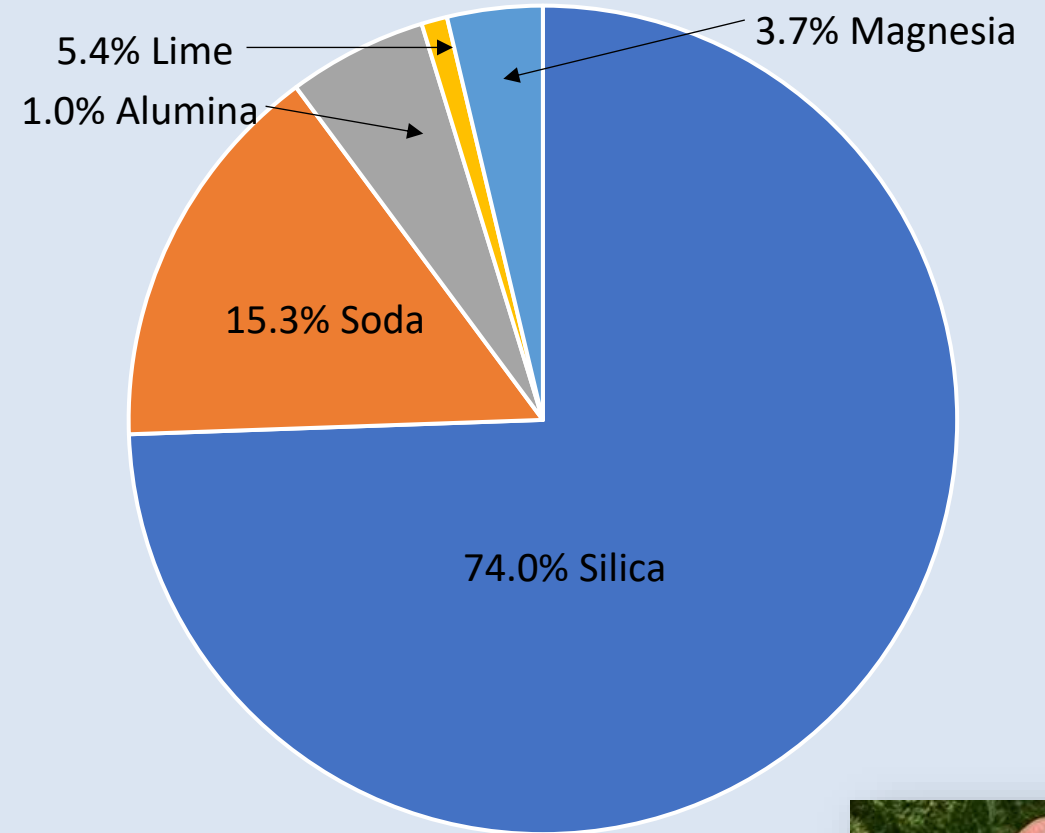
# LET'S HAVE A CLOSER LOOK AT GLASS

Most glass consists of silica sand and additional minerals such as sodium and calcium added to lower the melting point and obtain the desired physical properties. For example, glass containers typically contain:



*Metals or metal combinations are added to create coloured glass, for example, chromium (dark green or black), cobalt (blue), etc.*

Glass Container Composition (Pant et al 2014)



– Quartz is around 90% silica



# PHYSICAL PROPERTIES OF CRUSHED GLASS

- If crushed glass is considered as a replacement for natural aggregates, we must first understand (quantify) its physical and mechanical characteristics. Standard laboratory testing for aggregates can accomplish this, and considerable work has been done by others to date.
- The physical properties of crushed glass can then be compared with more “traditional” materials such as crushed limestone which is commonly used for construction applications in southern Manitoba.

## PHYSICAL PROPERTIES

- Shape
- Water Absorption
- Specific Gravity
- Unit Weight (compaction)
- Hydraulic Conductivity (permeability)

## MECHANICAL PROPERTIES

- Resilient Modulus
- Shear Strength

# PREVIOUS STUDIES (A SMALL SAMPLING)

- Mohsenian (2019) compared the physical and mechanical properties of recycled glass with crushed limestone focusing on using unbound recycled glass as a partial replacement for unbound granular aggregates in pavement structures.
- Wartman (2004) looked at select engineering characteristics of crushed glass.
- TREK (2014) looked at the use of recycled crushed glass as an aggregate in a report for Tetra Tech.

# TREK (2014)

- Sieve analysis and hydraulic conductivity testing completed on samples of 25 mm crushed glass from stockpiles at the Brady Road Landfill (BRLF).
- The largest portion of the recycled glass (cullet) was comprised of fragments from broken empty glass food and beverage containers.
- Also contained plastic, paper, miscellaneous metal and organic matter. Fragments from ceramics and plate glass were evident in small amounts.
- Although the debris comprised a relatively small percentage of the total sample mass, its presence is visually significant.
- Laboratory testing results were compared with published data.

# CRUSHED GLASS SAMPLE COLLECTED FROM BRADY ROAD LANDFILL



25mm Crushed Glass Sample From BRLF (AS RECEIVED)



Visible debris > 5mm removed from sample

# Particle Size Fractions From Mechanical Sieve Analysis

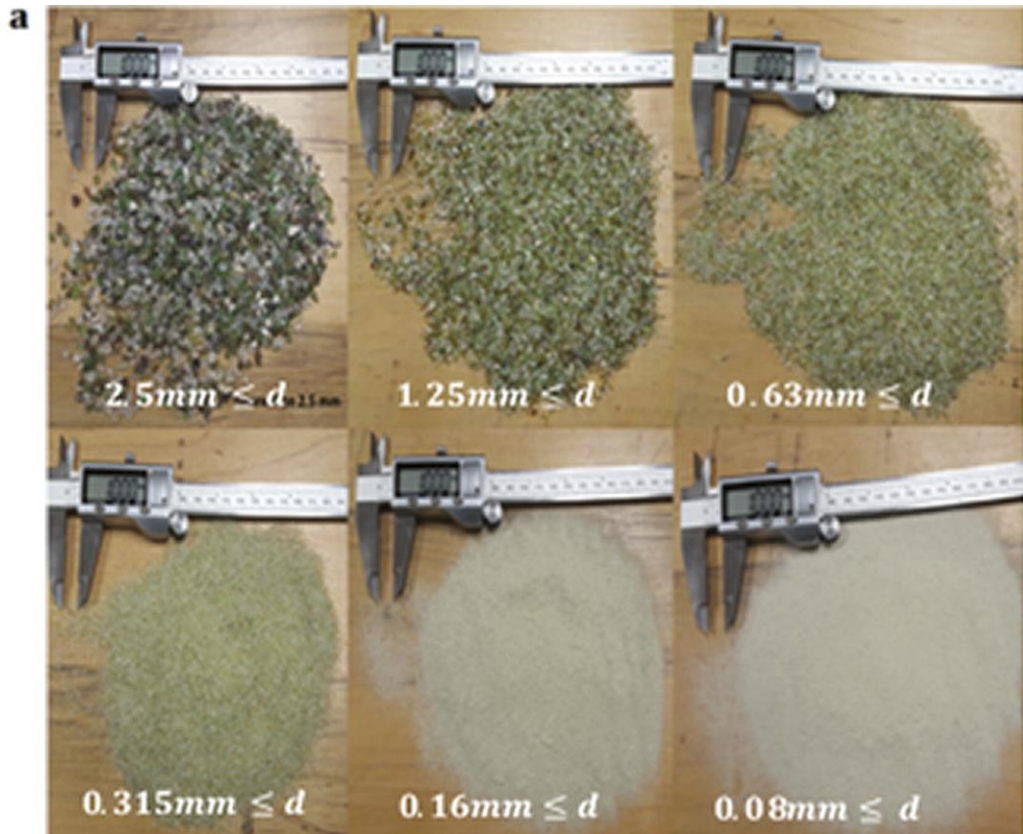
- ~ 80% gravel size and ~20% sand size particles
- Glass fragments < 10mm (~60% of the sample) resemble natural aggregate in shape & angularity.
- Fragments > 10mm (~40% of the sample) have some remnants of the original container shape (curved, flat, or smooth surface)



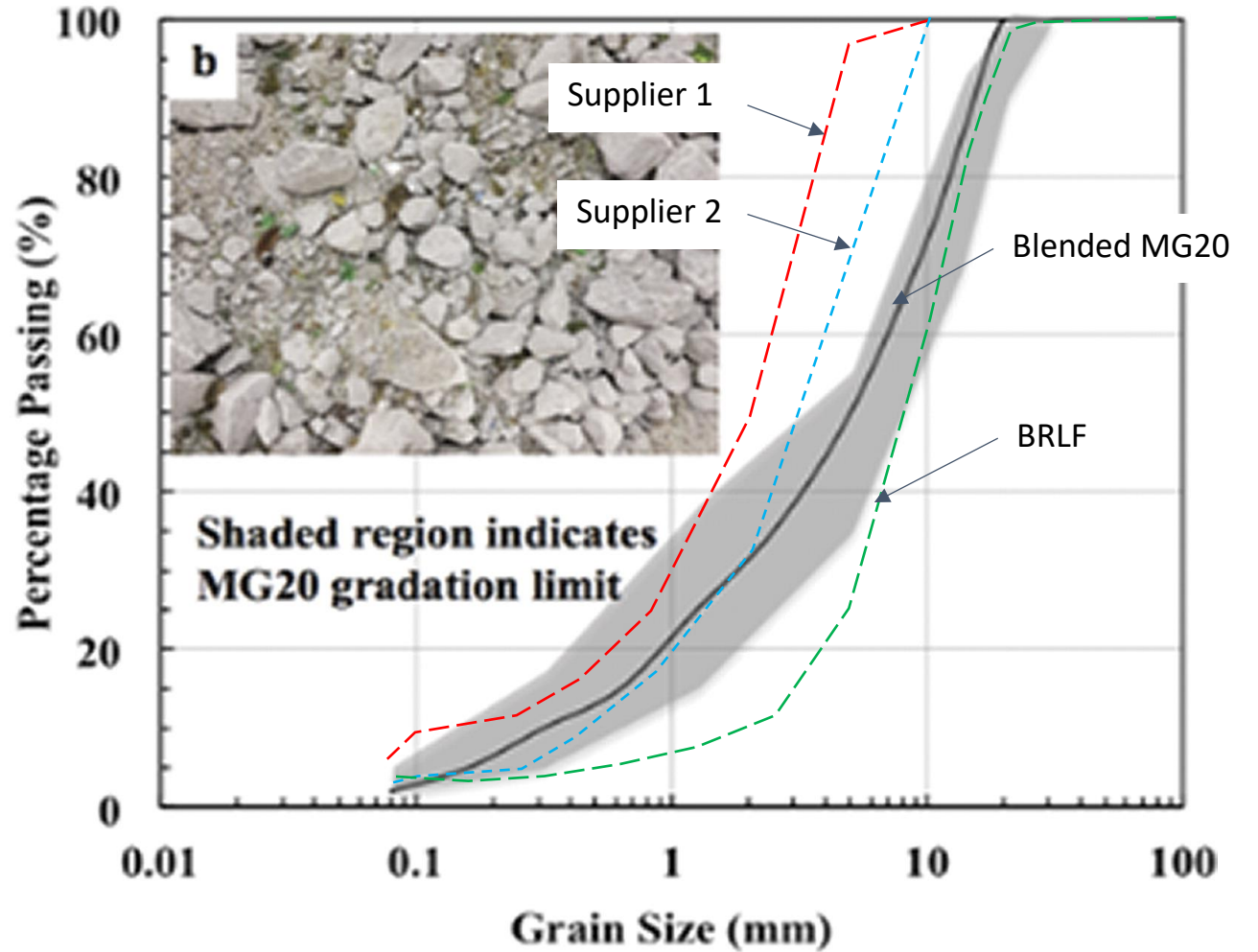
## MOHSENIAN, ET AL, 2019

- Two types of material investigated: Recycled glass (RG) of particle size 0-5mm and crushed limestone (LS) of particle size 0-20mm.
- Three blends of RG and crushed limestone were evaluated based on ratios between 25% and 100% and satisfying the gradation specification for Granular base (MG20) in Quebec.

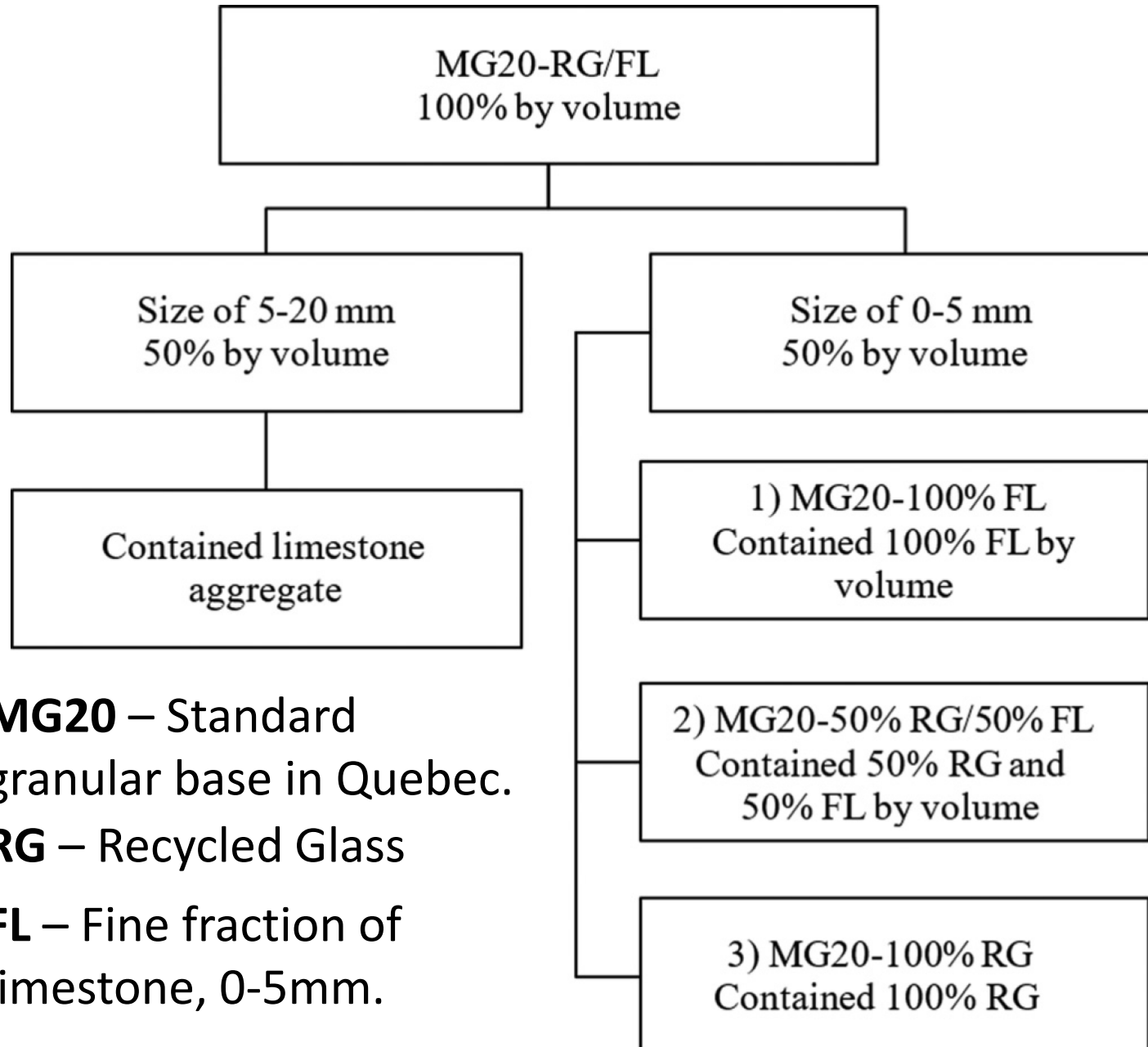
# RG Particle Sizes



# Gradation Curves



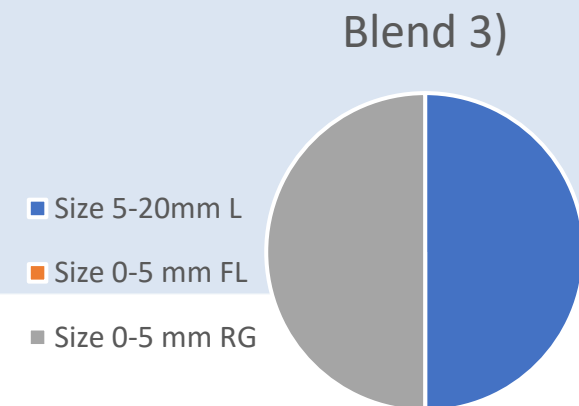
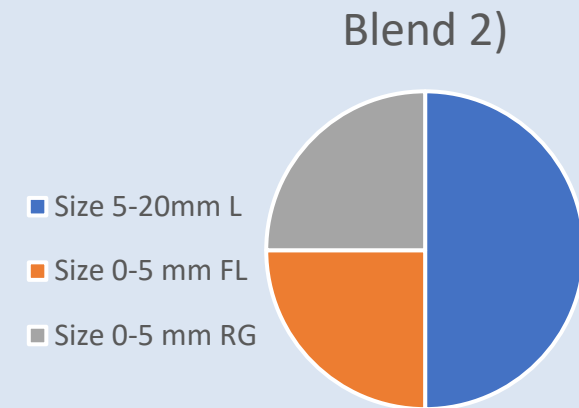
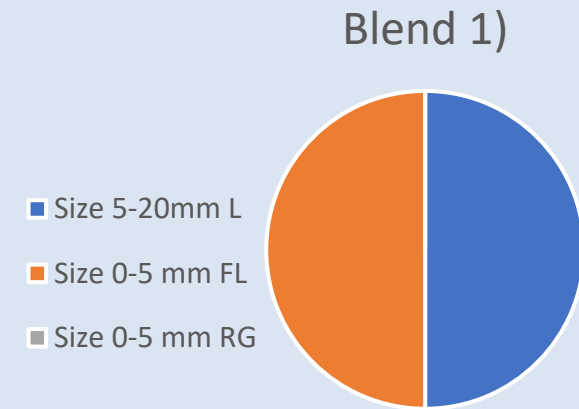
# Size Categories for Three Blends (modified from Mohsenian et al 2019)



**MG20** – Standard granular base in Quebec.

**RG** – Recycled Glass

**FL** – Fine fraction of limestone, 0-5mm.



# SHAPE PROPERTIES

The angularity and surface texture of RG and LS were indirectly assessed using the Flow Index Test:

Grain Size (d)	RG	LS
$1.25 < d < 2 \text{ mm}$	104	149
$0.63 < d < 1.25 \text{ mm}$	82	115
$0.315 < d < 0.63 \text{ mm}$	80	94

*CONCLUSION* - Flow Index of limestone is higher than for recycled glass due to higher angularity or rougher surfaces of particles.

# SHAPE PROPERTIES

X-ray CT scan was used to further investigate particle shape.

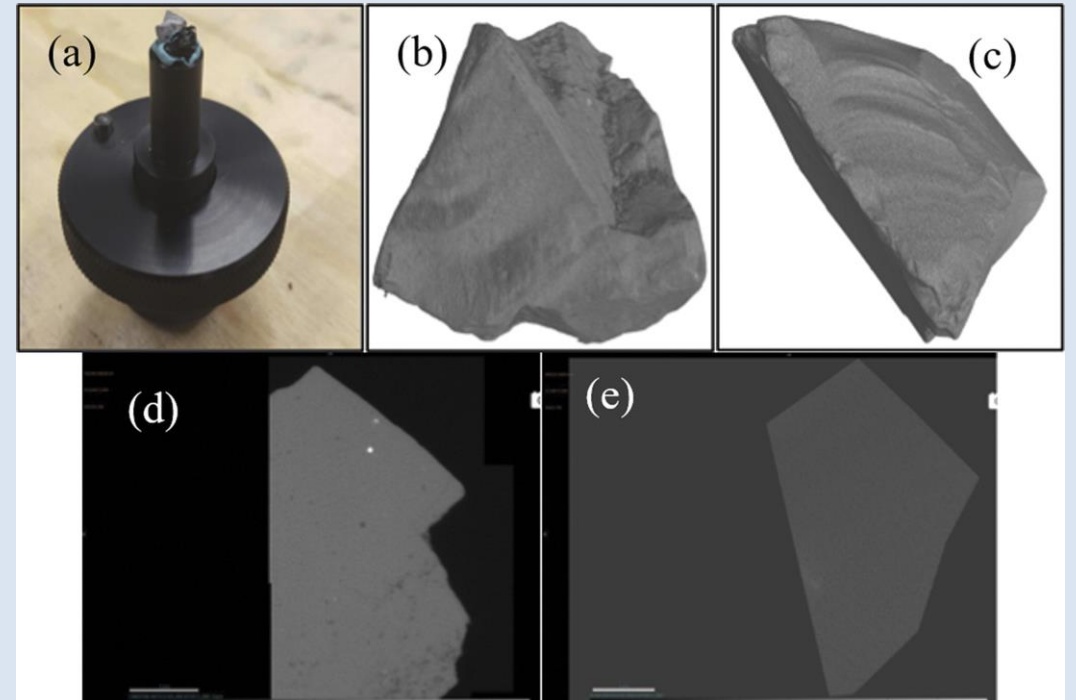
## CONCLUSIONS

- Recycled glass particle has a nonporous smooth texture. Limestone particle has rough surface with some porosity evident (~2.7%)



*Porosity ( $n$ ) is the ratio of the pore volume to the total volume: Higher  $n$  means more water can be absorbed..*

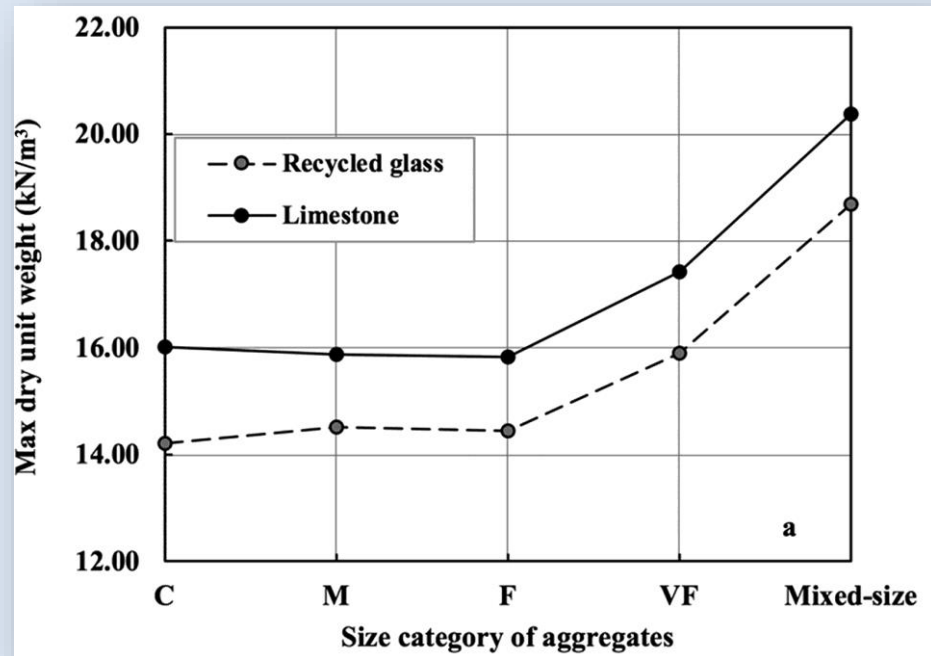
- (a) RG and LS particles prepared for X-ray CT;
- (b) 3-D image of LS
- (c) 3-D image of RG
- (d) and (e) gray spots detected in LS and RG particles respectively.



# SPECIFIC GRAVITY

- The results of specific gravity tests indicated that the limestone aggregate had higher values (2.761) than the RG aggregate (2.491).

# UNIT WEIGHT

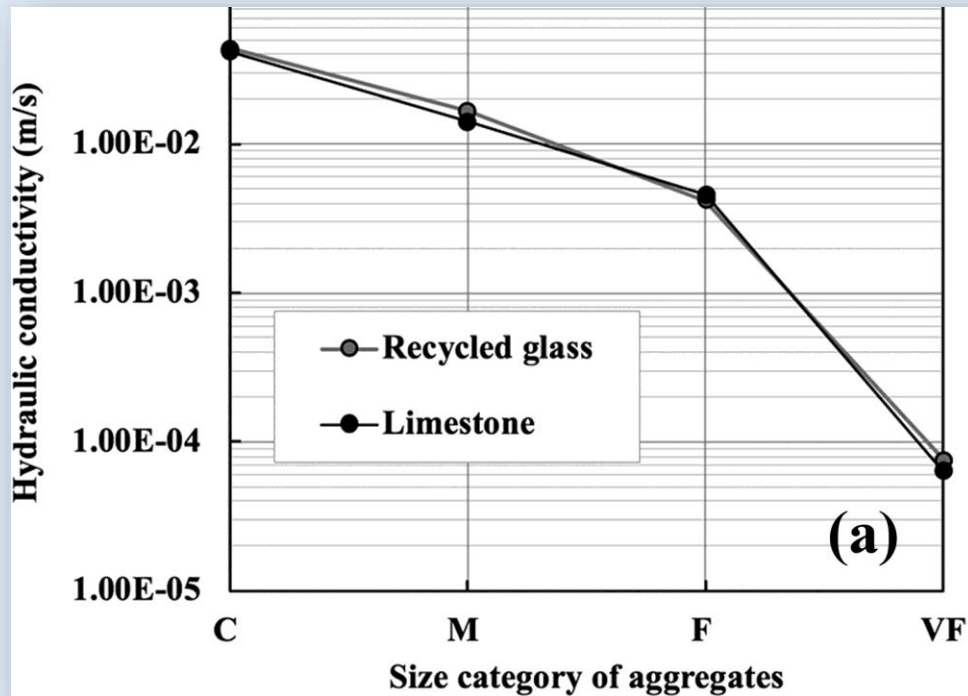


- Maximum dry unit weights of LS are ~ 10% higher than for RG - not surprising given the ~ 10% higher specific gravity for LS.
- Negligible breakdown occurred during vibratory compaction for both LS and RG aggregates.

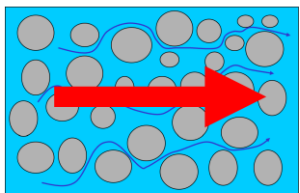
**Specific Gravity** is the ratio of the weight of a particle and the weight of an equal volume of water.  
**Unit Weight** is the ratio of the weight of the material and the volume it occupies.



# HYDRAULIC CONDUCTIVITY (PERMEABILITY)

Hydraulic conductivity (K) tests were performed to measure the ability of liquid to flow through the porous media.



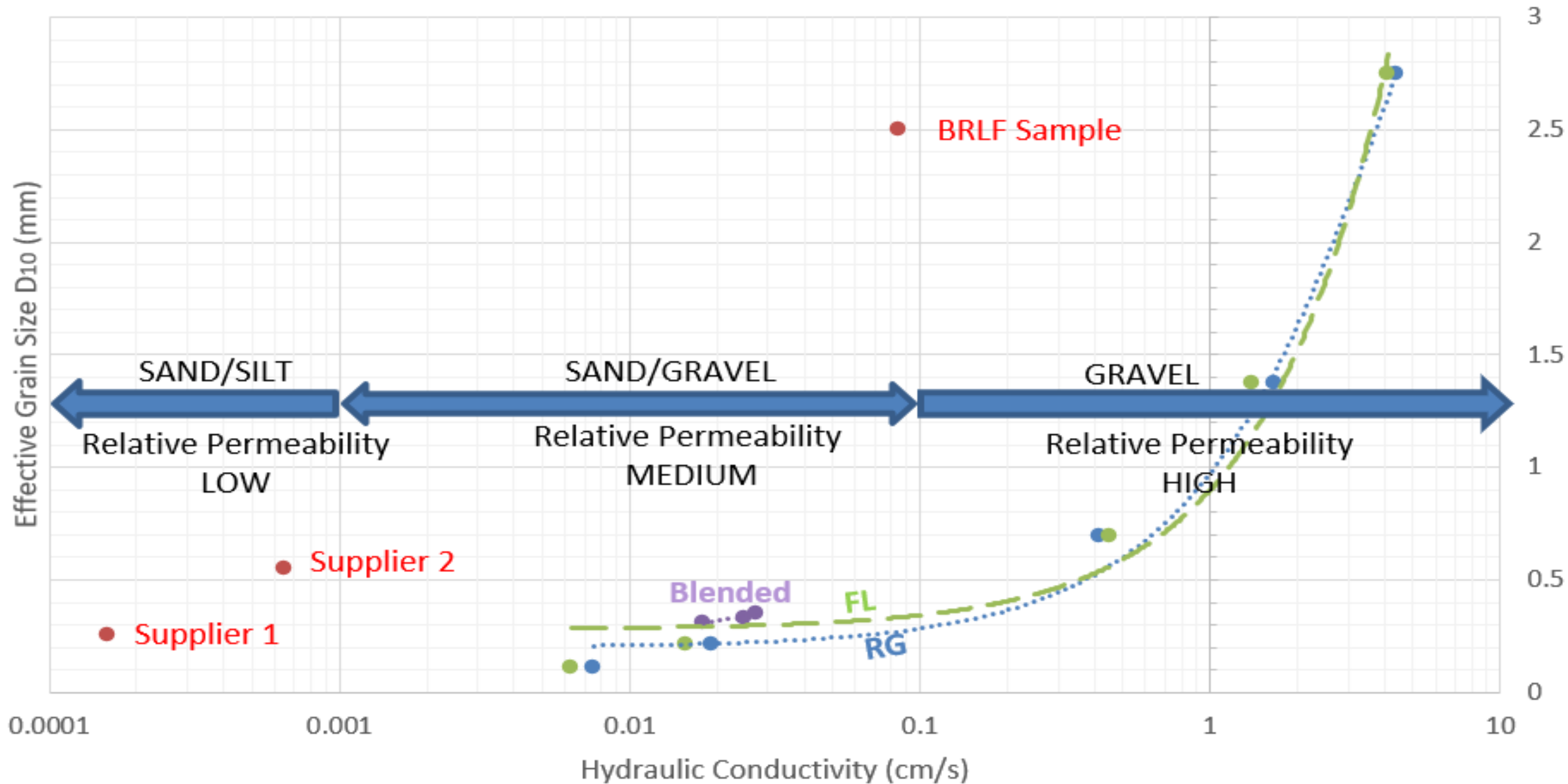
- Smaller particle size = lower measured hydraulic conductivity.
- Little difference in K between RG and LS for each of the grain sizes.
- All size ranges of RG show good potential to replace natural aggregate where drainage is important.



Actual flow paths   
Continuum approach 

*Darcy's Law for flow of a fluid through a Porous Media:  $Q = kiA$ .*

# Hydraulic Conductivity vs Effective Grain Size $D_{10}$



# MECHANICAL PROPERTIES

- Resilient modulus ( $M_r$ ) ranges from 100-400 Mpa which is similar to that of crushed natural aggregate (100 – 500 Mpa).
- Direct shear testing shows internal friction angle of crushed glass ranging from 58 – 68 degrees. Triaxial testing showed 47-48 degrees with small amount of “apparent” cohesion, perhaps due to glue residue. These can be compared to values ranging from ~ 40 to 60 degrees for natural aggregates.

# DURABILITY AND WEATHERING

- Los Angeles (LA) Abrasion values of ~ 25% were measured, slightly higher than for most mineral aggregates but below the maximum 30-35% often specified. Other authors have reported values as high as 40% but this may depend on the particle size.
- Crushed glass is not as susceptible to freeze-thaw related degradation compared to many natural aggregates (e.g., limestone). Soundness loss values of 6-7 % were reported for Suppliers 1 and 2 respectively which is well below the 12% limit often specified for coarse aggregates.

# GENERAL OBSERVATIONS

- Many of the engineering properties of crushed glass are comparable to properties of crushed natural aggregate.
- Crushed glass shows negligible absorption which will inhibit freeze-thaw degradation.
- The hydraulic conductivity of crushed glass suggests it could be used for applications where drainage is important.
- Bulk glass quality is affected by the commingled recycling stream which introduces contaminants. This can impact on reuse/recycling possibilities.

# GENERAL OBSERVATIONS

- Recent studies show that RG could potentially replace up to 100% of the fine fraction (0-5mm) of limestone and contribute to an increase in drainage for road base aggregates. Blending specifications have been developed in other jurisdictions.
- Moisture–density (Proctor) curves exhibit the characteristic convex shape of natural aggregates, suggesting that crushed glass compacts similarly to natural aggregates (Wartman et al, 2004). The flatness of the Proctor curves indicate stable compaction characteristics and good workability over a wide range of water contents.

# SOME POTENTIAL SECONDARY END-MARKETS

- Crushed glass-natural aggregate-recycled asphalt pavement (RAP) mixes.
- Partial replacement of natural aggregates in road base (although to the speaker's knowledge, this has not been officially approved anywhere in Canada).
- Partial replacement for crushed limestone in riverbank stabilization projects e.g., rockfill columns, shear keys, etc. (recycled concrete aggregate was recently used for trial-columns in Winnipeg).

# SOME POTENTIAL SECONDARY END-MARKETS

- Filler aggregate for French drains, leachate collection systems, drainage blankets, etc.
- Reflective paints and abrasives.
- Clay soil modification (Mohamed et al, 2022).
  - Consistency
  - Compaction characteristics
  - Shear strength
  - Swelling characteristics
  - CBR

# REAL OR PERCEIVED BARRIERS TO USING RECYCLED GLASS



*A performance specification defines the functional requirements*

- Contracting mechanisms,
- Time-tested specifications (If it aint broke...)
- Existing nonperformance (material specific) specifications,
- Minimum acceptable density criteria,
- Material contamination,
- Insufficient knowledge of geotechnical characteristics,
- Risk aversion out of concern for Public safety,
- Resistance to change unless a distinct cost and/or performance advantage can be realized (which may apply in regions with limited natural aggregate resources)



ANY BURNING  
QUESTIONS??