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RECYCLED MATERIALS IN CONCRETE APPLICATIONS - BENEFITS FROM WASTE FREE ONTARIO ACT

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Abstract: According to Statistics Canada, the cost of waste management by local governments increased from $1.8 billion (2004) to $3.2 billion (2012). Ontario's Waste Free Ontario Act (WFOA, 2016) aims to shift responsibility and cost of recycling programs and materials from the communities and municipalities to manufacturers of waste products. This will motivate manufacturers to find alternative uses for the nearly 12 million tonnes of waste generated in Ontario annually. One potential alternative is to reuse post-consumer products in the manufacture of concrete products. Current research focusses on making concrete "greener" by replacing its traditional components with environmentally advantageous alternatives. The goal of this study is two-fold. First, a list of waste materials potentially useful in concrete production impacted by WFOA is presented. Second, a summary and literature review is presented of the five most important waste materials impacted by the WFOA, identified as useful in cement and concrete production. These five waste materials are glass, polyethylene terephthalate (PET), polystyrene, paint and tires. A detailed literature review of past and current concrete research done on the five materials is presented. Data analysed on quantity of waste generated versus diverted from landfill indicate that waste tires has the most practical application in the concrete production and construction industry in general. It is proposed that further research be conducted to investigate the combination of, say, waste rubber and latex paints in roadwork applications for weather resistant, sound absorbing road surfaces.

Keywords: Waste Free Ontario Act, concrete, tires, paint, glass, polystyrene, PET

1 INTRODUCTION/ LITERATURE REVIEW

Ontario generates nearly 12million tonnes of waste annually, and three-quarters of this goes to landfill (Statistics Canada, 2014). To tackle the problem of waste generation and disposal, fight climate change and reduce greenhouse gas pollution, the Ontario legislature enacted the Waste Free Ontario Act (WFOA, 2016), which consists of the Resource Recovery and Circular Economy Act and the Waste Diversion Transition Act. WFOA aims at achieving a "circular economy" in Ontario. The goal is to minimize the use of raw materials and energy during the manufacturing process, and to ensure that when a product reaches the end of its life, it is re-used to create further value (WFOA, 2016). This will drive innovation among producers, bring more opportunities to businesses and provide incentives for future investment (MOECC, 2017). Given the projected population growth and economic trends, it is forecasted that Ontario will need 16 new or expanded landfills by 2050 if no progress is made in resource recovery and waste reduction. Improved waste and resource recovery will also reduce greenhouse gas emissions and ensure potentially harmful materials are properly managed (WFOA 2016, MOECC 2017).

The following timeline is being used by the Ontario government to achieve a waste-free province. The term "we" in the flow chart in Fig. 1 represents the Ministry of the Environment and Climate Change.

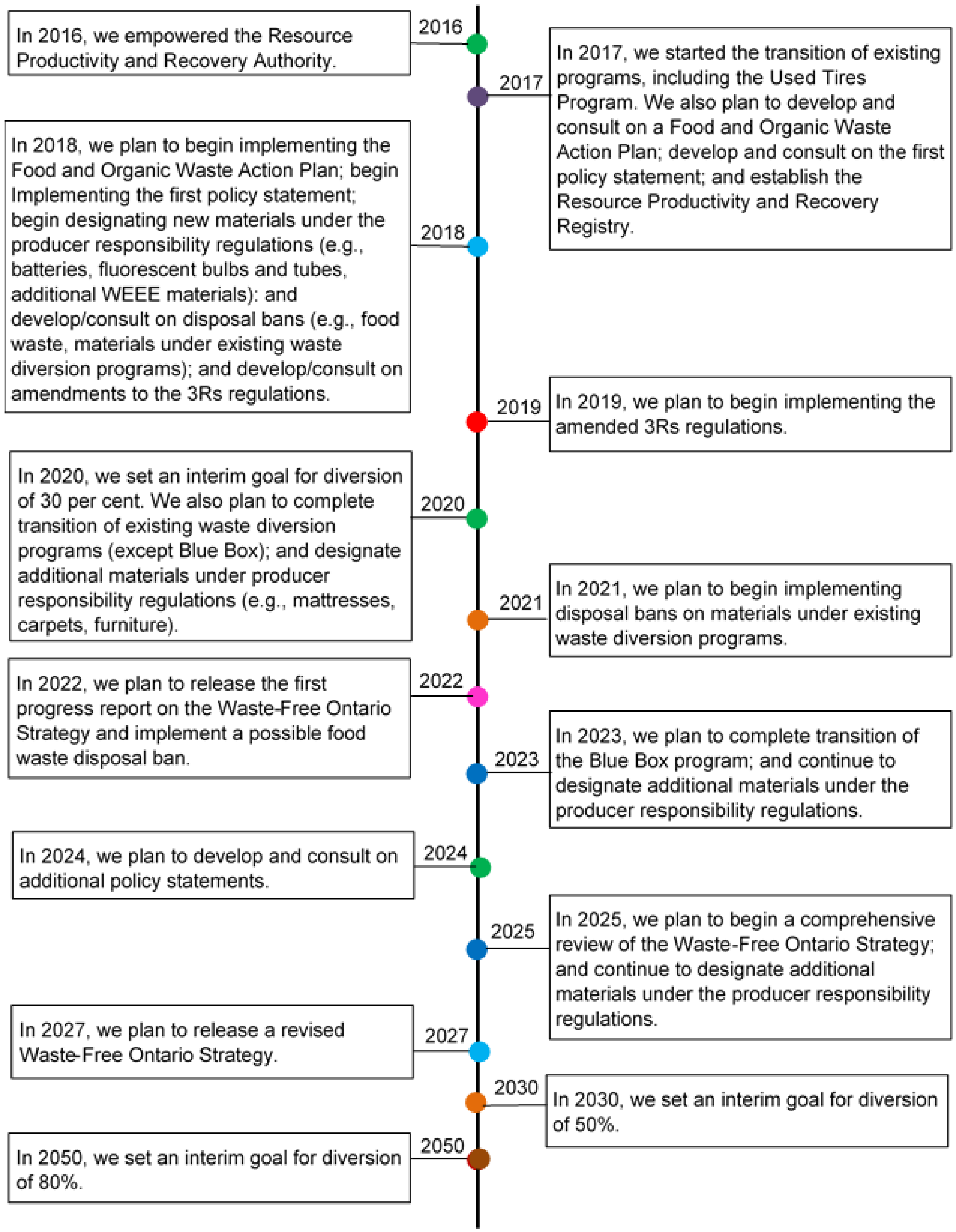

Fig. 1

Accessed Jan. 10, 2019 https://www.ontario.ca/page/strategy-waste-free-ontario-building-circular-economy

2 RESEARCH OBJECTIVE

The overall objective of this study is to establish a reliable database of recyclable materials that have the most practical application in the concrete production and the construction industry in general.

The specific goals of this research are: (a) to present a survey summary of waste materials that will be impacted by WFOA which are potentially useful in concrete production; (b) present a survey summary of the five most important waste materials impacted by the WFOA; which have been identified as useful in cement and concrete production; (c) to present a literature review of past and current concrete research done on the five materials; and (d) to propose future research investigations that combine some of the five useful waste materials in various concrete mixes to yield desired properties in concrete performance.

3 METHODOLOGY

An in-depth literature review was conducted of the new Act (WFOA, 2016), and work done by researchers on applications of recycled post-consumer materials in concrete production. Concrete industry professionals, academics, and researchers were consulted to help develop a better understanding of current trends in concrete innovation. This information was useful in compiling the databases presented.

4 MATERIALS IMPACTED BY WFOA (2016)

To achieve the goals of a circular economy in a seamless manner, existing waste diversion programs will end under the Waste Diversion Transition Act (2016), and regulations under the Resource Recovery and Circular Economy Act (2016), which will ensure that producers are fully responsible for the materials under the existing programs, will be implemented at the same time (MOECC, 2017).

4.1 RECYCLE MATERIAL PROGRAMS

Tables 1a and 1b lists materials impacted by WFOA, which are of interest to this study. Facilitated by the Waste Diversion Act (2002), Ontario has four waste diversion programs in place. These programs divert roughly one million tonnes of waste annually from landfills. Table 1a lists all materials under the four waste diversion programs, developed and operated by the following three industry funding agencies. Once requirements under the new Act come into force, existing programs and the industry funding organizations that operate them will be eliminated (MOECC, 2017):

- Blue Box operated by Stewardship Ontario
- Municipal Hazardous or Special Waste (MHSW) operated by Stewardship Ontario
- Waste Electrical and Electronic Equipment (WEEE) operated by Electronic Stewardship
- Used Tires operated by Ontario Tire Stewardship

Table 1b lists the following materials of the Industry Stewardship Plans approved under the Waste Diversion Act, 2002 (MOECC, 2017):

- Used Paints and Coatings
- Pesticides, Solvents and Fertilizers
- Automotive Materials Stewardship
- Soda Stream

Some waste diversion programs handle materials that are not suitable for use in the concrete industry. For example, the Industry Stewardship Plan (ISP) for SodaStream canisters (i.e. pressurized CO_2 canisters), is not of interest to this study because their soda cylinders are virtually infinitely reusable (MOECC, 2017).

Table 1a: Materials Under The Waste Diversion Act (2002)

Program	Blue Box	Municipal Hazardous or Special Waste (MHSW)	Waste Electrical or Electronic Equipment (WEEE)	Used Tires
Materials	Corrugated Cardboard	Corrosive products, flammable products or toxic products	Household Appliances	Used Tires
	Boxboard	Flammable hazards, corrosive hazards or toxicity hazards	Information technology equipment	
	Gable Top Cartons	Corrosive waste	Telecommunication equipment	
	Tetra Pak Cartons	Ignitable waste	Audio-visual Equipment	
	Other Aluminum & Foil Packaging	Leachate toxic waste	Toys, leisure and sporting equipment	
	Empty Aerosol Cans	Reactive waste		
	Empty Paint Cans	Containers that contain anything referred to in clauses above		
	HDPE Containers			
	Glass, Other Bottles & Containers (#3, #4, #5, #7)			
	LDPE/HDPE Film (#2, #4)			
	Polystyrene Foam (#6)			
	Polystyrene Crystal (#6)			

Table 1b: Industry Stewardship Plans Materials Approved under Waste Diversion Act, 2002

Program	Used Paints and Coatings	Pesticides, Solvents, Fertilizers	Automotive Materials	SodaStream
Materials	Latex, Oil and solvent-based architectural coatings, including paint and stains (tinted or untinted) Solvents		Antifreeze Oil filters Oil Containers	SodaStream canisters

4.2 FINALIZED MATERIAL LIST

This study further reduced the list of the materials impacted by WFOA in Tables 1(a & b), by evaluating and identifying which materials are available in significant volumes, and reviewing available literature to see which materials have shown the most promise to contribute to innovation in the building and construction industry. The five materials (shown in Table 2) were chosen due to the fact that they are all impacted by the WFOA, can be the subject of variety of research studies, and can have great potential to influence innovation in the concrete industry.

Table 2: Five Waste Materials Suitable for Application in the Cement and Concrete Industry

Material	State	Use	Previous Program	Timeline to Implement WFOA
Glass	Crushed powder Crushed shards	Supplementary Cementitious materials Aggregate	Blue box	By 2023
PET (plastic bottles) (Polyethylene terephthalate)	Fibers shred Random shred Random shred	Aggregate Aggregate Asphalt aggregate	Blue box	By 2023
Polystyrene (packing foam)	Beads Foam	Aggregate Aggregate	Blue box	By 2023
Waste paint	Recycled paint Recycled paint Recycled paint	Replacing mixing water Green roof membrane green roof membrane	Municipal Hazardous or Special Waste (MHSW)	By 2020
Waste tires	Shredded Shredded Shredded	Aggregate Asphalt aggregate Engineered fill	Ontario Tire Stewardship (OTS)	Already in place

5. DISCUSSIONS: FIVE SELECTED WASTE MATERIALS

5.1 Recycled Glass

Glass, currently diverted from landfill by the Blue Box program will be fully phased out by 2023, and promises to be the most complicated to phase out since it is managed by a wide variety of private companies and municipalities (MOECC, 2017). Recycled glass, previously researched at Fanshawe College (Kalloush et al., 2016) in the form of crushed powder or shards, provides many other uses in concrete and cement manufacturing. Figures 2a and 2b show the recycled crushed mixed glass samples used for the investigation at Fanshawe College in 2016. While the Fanshawe research focused on the use of recycled glass as an aggregate, the material can also be used as supplementary cementitious material (SCM) (Federico, L.M. and Chidiac, S.E., 2009). Research has shown potential for using finely ground glass to supplement raw materials in cement production and as an SCM in concrete mixes (Shi, C. & Zheng, K., 2007). Work has also been done to determine the limits to which glass can replace other raw materials, and the suitability of different chemical compositions of various glass types (Chen, G. et al., 2002).

Fig. 2(a): Coarse glass

Fig. 2(b): Fine glass

5.2 Recycled PET

Recycled plastics, which are also currently part of the Blue Box program comes in several forms, including high-density polyethylene (HDPE), low-density polyethylene (LDPE), polystyrene and polyethylene terephthalate (PET). Only two of these were selected due to their significance from previous research findings, and the quantity of materials available. The first, PET, is most commonly used in manufacturing plastic bottles, of which there are large supplies in recycling streams. Use of shredded PET in concrete research has focused on its use as an aggregate. Interesting research has been done on the properties of concrete with PET aggregate, investigating its drainage, insulative, and durability qualities (Siddique, R. et al., 2008). Shredded PET bottles were found to improve the insulative performance of concrete by 18.16% compared to concrete without PET (Yesilata, B. et al., 2009). Other studies found that the addition of recycled PET fibers greatly improved the concrete's ductility, while negatively impacting compressive and tensile strength (Kim, S. B. et al., 2010). PET has also been experimented with as an aggregate in asphalt. This material is interesting to research because, PET bottles unlike glass bottles, are harder to reuse. Coming up with novel ways to reuse PET bottles would be beneficial to recycling efforts. Figure 3 shows the different types of recycle plastic bottles surveyed.

Fig. 3: PET (plastic) bottles

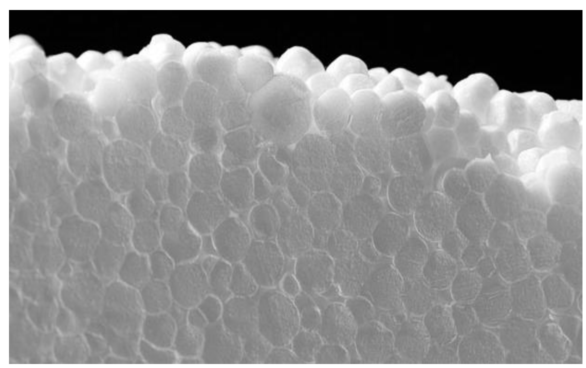

Fig. 4: Recycled polystyrene (packing foam)

Fig. 3 Sourced, Jan 31 2019: http://www.bluewww.fallsco.com/materials.html
Fig. 4 Sourced, Jan 31 2019: http://www.bluemaize.net/im/arts-crafts-sewing/plastic-bottles

5.3 Recycled Polystyrene

The second set of plastic, polystyrene is one that has less research done on it, but presents interesting possibilities. Polystyrene is manufactured as foam or as a hard brittle solid plastic (beads). The foam variety, more properly known as expanded polystyrene (EPS), can be modified using heat to reduce its volume by approximately 20 times to create modified expanded polystyrene (MEPS) (Kan, A. and Demirboga, R., 2009). MEPS can be used to improve the insulative properties of concrete when used as an aggregate, although this type of concrete may not be suitable for use in load-bearing structural elements (Kan, A. and Demirboga, R., 2009). EPS can also be found in beads form, and has been used as experimental aggregates to form lightweight concrete (Ravindrarajah, R. S. and Tuck, A. J. 1994). Some of the research investigated EPS beads in conjunction with common SCM's, e.g. Silica Fume (Babu, K. G. and Babu, D. S., 2003) and Fly Ash (Babu, D. S. et al., 2005). Other research investigated the compressive strength and fire resistance of concrete with EPS beads. Mixes with lower EPS volume were more fire resistant than higher volume mixes. The opposite relationship was observed for thermal conductivity. Higher volumes of EPS reduced the compressive strength (Sayadi, A. A. et al., 2016). Figure 4 shows a sample of recycled polystyrene.

5.4 Waste Paint

Waste paints are currently diverted from landfills by an industry stewardship plan that is set to be completely replaced by 2020. Research done at Western University using waste latex paint (WLP) investigated replacing a portion of mixing water with WLP in concrete (Nehdi, M. and Sumner, J., 2003).They found that replacing 15% of mixing water with WLP resulted greater workability of the mixture, as well as greater tensile strength. Although compressive strength was decreased, researchers noted concrete mixes with WLP may be adequate structural applications (Mohammed, A. et al., 2008).The researchers also theorized that the mix would improve durability with respect to freeze-thaw. Figure 5 shows samples of waste paint.

Fig. 5: Waste Paint

Fig. 6: Waste Tires

Fig. 5 Sourced, Jan 31, 2019:http://www.paintdenver.com/managing-leftover-latex-paint.
Fig. 6 Sourced, Jan 31, 2019:http://www. shutterstock.com/image-photo/waste-heap-old-tyres-rubber-recycling

5.5 Waste Tires

The final material selected is waste tires. Its diversion program replaced in the early stages of implementing the WFOA. It is one of the materials with the most potentially practical applications. Waste tires can be shredded to be used as concrete aggregate, asphalt aggregate, or as backfill (Pierce, C. E. and Blackwell, M. C. 2003, Lee, J. H. et al., 1999). As an aggregate, waste tire rubber yields better durability and vibration absorbing properties (Shu, X. and Huang, B., 2014). Figure 6 shows waste tires useful as aggregates in concrete production.

5.6 Volume of Waste Generated and Diverted from Ontario Landfill in 2014

Table 3 and Figure 7 show the quantities of waste generated and diverted from landfill in Ontario for 2014. These wastes include curbside household garbage, construction waste and wastes generated by businesses and institutions. Of the 844,504 tonnes of blue box wastes generated, two thirds was diverted from landfills (Stewardship Ontario, 2015). Of the 99, 799 tonnes of waste glass generated, about 87% was diverted from landfills. It is important to note that glass cullets are not efficiently recyclable into glass bottles. Plastics are increasing in their percentage contribution with respect to generation and recovery. They are highly reusable and are relatively easy to recycle (Lakhan, C., 2015). Table 3 shows that while 59% of PET (plastic bottles) was diverted, only 3% of polystyrene (packing foam) was diverted. For waste paints, Table

3 shows the data for all paints, coatings and aerosols. Of the 9360 tonnes of waste paint generated under the Municipal Hazardous or Special Waste (MHSW) program, about 35% was diverted from landfills. In 2014, of the 109,414 tonnes of tires supplied into the market place under the Ontario Tire Stewardship (OTS) program, about 72% was diverted from landfills. Thus, waste tire constitutes one of the highest diversion quantities and rates. Thus, waste tires have the most practical application in the concrete production and construction industry (OTS, 2014).

Table 3: Quantities of Waste Generated and Diverted from Landfill in Ontario for 2014

Material	Program	Quantity Generated (Tonnes)	Quantity Diverted (Tonnes)	Quantity Diverted (%)
Total Waste	Total Waste	11,600,000	--	--
Total Blue Box	Blue Box	844,504	566,082	67%
Glass (mixed)	Blue Box	99,799	87,224	87%
PET (plastic bottles)	Blue Box	52,539	31,135	59%
Polystyrene (packing foam)	Blue Box	57,400	1,448	3%
Waste Paint	MHSW	9,360	3,315	35%
Waste Tires	OTS	109,414	78,404	72%

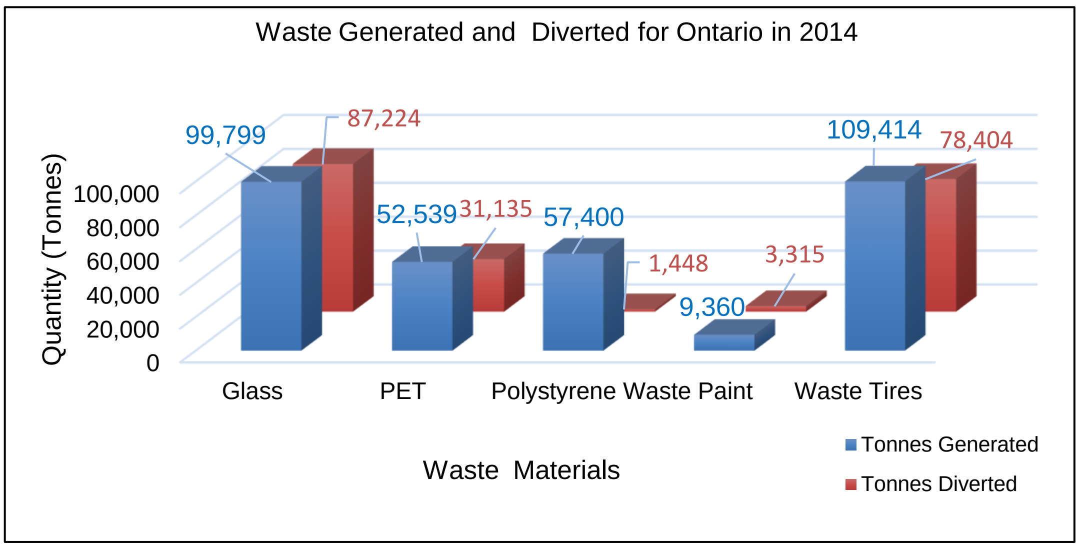

Fig. 7: Quantities of Waste Generated and Diverted from Landfill in Ontario for 2014

5.7 Summary of Results

This research has resulted in the assembling of databases and other information which will be the basis of future concrete research that will incorporate the five selected waste materials; recycled glass, PET, polystyrene, paint and tires. This includes an overview of relevant legislation, past research investigations and findings involving the five selected waste materials.

Previous research has shown potential usage of finely ground glass to supplement raw materials in cement production and in concrete mixes as supplementary cementing material. Limits for utilizing glass as a raw material replacement in concrete mixtures were established. In addition, the suitability of different chemical compositions of various glass types was evaluated.

Out of all plastic wastes, PET and polystyrene were selected due to the promising findings of previous research studies and the high volume available of these materials. While most research using PET in concrete has focused on its use as a conventional aggregate, other researchers have investigated its drainage, insulation, and durability properties. Other studies found that the addition of recycled PET fibers greatly improved the concrete's ductility, while negatively impacted the compressive and tensile strength.

The impact of EPS (polystyrene) beads on the fire resistance, thermal conductivity and compressive strength on concrete was investigated. Mixes with lower EPS volume exhibited higher fire resistant than mixes with higher EPS volume, and the opposite relationship was observed for thermal conductivity. Higher volume of EPS in concrete mixes was found to reduce the compressive strength greatly.

Research performed at Western University replaced concrete mixing water with waste latex paint (WLP), which resulted in enhanced workability and tensile strength. Although compressive strengths decreased, researchers noted that concrete mixes with WLP may be adequate for certain structural applications, and could improve durability with respect to freeze-thaw resistant.

Waste tires can be shredded and used as concrete aggregate, asphalt aggregate, or as backfill material. As aggregates, waste tires rubber is known to yield good durability and vibration absorbing properties when used on roads and sidewalks. Since waste tires are available in economic quantities, it is the materials with the most practical application in concrete production and the construction industry in general.

6. CONCLUSIONS/ FUTURE RESEARCH

This study shows that recycled glass, PET (plastic bottles), polystyrene (Styrofoam), waste tires and recycled paints potentially have various uses in production of concrete. Glass, which is expensive to recycle, can be used to replace a concrete additive (silica fume), which is becoming scarcer in Ontario, saving money for both glass and concrete producers. Plastic bottles, Styrofoam and tire crumbs can result in better insulation properties in non-structural concrete. An interesting avenue of future research would be to investigate the combination of these materials. For example, waste rubber and latex paints, with the proper ratios, could be used in roadwork applications for weather resistant, sound absorbing road surfaces.

7 ACKNOWLEDGEMENT

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