Building Tomorrow's Society
Bâtir la Société de Demain

Fredericton, Canada
June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

USE OF EVA FOAM IN PORTLAND CEMENT CONCRETE

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Abstract: EVA foam is a copolymer, composed of Ethylene and Vinyl Acetate, that is used in several industrial products. It is known to be lightweight, moisture resistant, chemical insulating, heat insulating and energy absorbent. During the manufacturing of EVA products, such as athletic footwear, swimming mats, etc., large quantities of EVA waste is generated. This waste is non-recyclable and poses various health harms when burnt, such as severe irritation to the eyes, skin and mucous membrane. Thus, it is currently being disposed of in landfills, as this deems to be the easiest way for manufacturers to handle the EVA waste. This study aims to assess the incorporation of EVA Foam as a non-recyclable; toxic solid waste in Portland cement concrete. Thirteen different mixes were poured using different sizes of EVA Foam which are 9.5, 19 and 38mm. These sizes were used as replacement for coarse aggregates by the following percentages 5,10,15 and 20%. Concrete with the replaced EVA aggregates demonstrated a decrease in compressive strength, but showed little or no difference in flexural strength. EVA concrete demonstrated a good potential in being considered as lightweight concrete as well as an abrasion resistant one. Although the results of the water penetration test showed a higher water penetration for EVA concrete, EVA concrete seems to be a good candidate for thermal insulation applications. Building on these tests, EVA concrete did not seem to witness any significant change with regards to its fire resistance properties. In addition, the incorporation of EVA in concrete seemed to make it more ductile as opposed to its brittle nature. Moreover, the high replacement percentages showed an initial potential for pervious concrete applications.

1 INTRODUCTION

EVA is short for Ethylene Vinyl Acetate, which is a co-polymer of ethylene and vinyl acetate with the chemical formula, $C_6H_{10}O_2$ (Seedahmed A.I., 332). Ethylene Vinyl Acetate is known for its following properties: moisture resistance in its raw form, light weight, thermal insulation and chemical resistance.

These properties are what make it widely used in various industries including the sports, and healthcare industries. It is especially widely used in the footwear industry both globally and locally. According to a study by UNIDO, there are 17 billion pair of shoes produced globally every year, with each million of which generating approximately 80 tons of waste. Out of this amount, EVA Foam waste represents 14%, summing up to a total of 194,000 tons produced every year (UNIDO). In a more focused context, primary research suggests that the footwear industry in Egypt generates an annual sum of 28,000 tons of EVA waste.

Given that EVA foam is considered to be a thermosetting material, recycling these amounts of waste requires special procedures that are quite expensive. Accordingly, these piles of waste end up being thrown in landfills, occupying large areas (Diana Lopes, 231). Not only does this option take up much space, it also negatively impacts the environment given that it is non-biodegradable and will need more than one thousand years to decompose.

1.1 Objective and Scope

In an attempt to reduce the environmental impact of such waste material and concrete, the creation of greener concrete using EVA waste was investigated. The experimental work was designed to assess the effect of replacing different percentages of coarse aggregates with EVA waste aggregate of various sizes on the concrete's performance. This was done through testing for the concrete's compressive and flexural strength, its permeability and resistance to abrasion. In addition, the concrete's thermal resistance, fire insulation, infiltration rate and modulus of elasticity were tested in light of EVA foam's properties.

2 EXPERIMENTAL PROGRAM

2.1 Materials

Cement: Ordinary Portland cement, Type I, was used with specific gravity of 3.15

EVA Foam: Sizes of interest: 9.5mm, 19mm and 38mm

The EVA waste is originally attained in the form shown in Figure 1. This form was then shredded using fabricated steel plates to acquire the specified sizes, a sample of which is shown in Figure 2.

Coarse Aggregates: Well-graded coarse aggregates with a SSD specific gravity of 2.66 was used

Fine Aggregates: Natural sand with a SSD Specific gravity of 2.5 was used

Water: Normal tap water was used in concrete mixing and curing

Super Plasticizer: 1% by weight of cement of Super plasticizer was used in order to increase the workability of the concrete mix

Figure 1: EVA Waste in its Original Form

Figure 2: EVA Waste After Shredding

2.2 Concrete Mix Design

Table 1: Mix Design

EVA Aggregate Size (mm)	Replacement Percentage (%)	Cement (kg)	Water (kg)	w/c	Fine aggregates (kg)	Coarse Aggregates (kg)	EVA Foam (kg)
-	0	350	175	0.5	650	1170	0
9.5	5	350	175	0.5	650	1111	46
9.5	10	350	175	0.5	650	1053	91
9.5	15	350	175	0.5	650	994	137
9.5	20	350	175	0.5	650	936	182
19	5	350	175	0.5	650	1111	46
19	10	350	175	0.5	650	1053	91
19	15	350	175	0.5	650	994	137
19	20	350	175	0.5	650	936	182
38	5	350	175	0.5	650	1111	46
38	10	350	175	0.5	650	1053	91

2.3 Tests

2.3.1 Fresh Concrete:

Tests were conducted on fresh concrete according to the designated ASTM standards. These tests were: slump, unit weight and air content.

2.3.2 Hardened Concrete

Compressive Strength: This test was conducted according to British Standards [BS 1881] for 150mmx 150mmx150mm cubes to find the 7 and 28-compressive strength. For each mix, three cubes were tested and the average strength was calculated.

Flexural Strength: This test was conducted according to ASTM Standards [ASTM C78] for 150mmx150mmx750mm beams to find the flexural strength after 28 days.

Water Penetration: This test was conducted according to German Standards [DIN 1048] for 150mmx 150mmx150mm cubes to find out the depth of water penetration under pressure.

Abrasion: This test was conducted according to ASTM Standards [ASTM C779] to determine the relative abrasion resistance of horizontal concrete surfaces. Each specimen of size 50mmx50mmx25mm was subjected to abrasive material on a rotating disk for three 2-minute intervals. This procedure was repeated with three samples of the same mix to obtain the average weight loss percentage.

2.3.3 Specialized Tests

Thermal Conductivity: The test was conducted according to ASTM Standards [ASTM C518] to cover the measurement of steady state thermal transmission through flat slab specimens 300mmx300mmx40mm using a heat flow meter apparatus. It measures the thermal conductivity (K) which is the ability of a material to conduct heat.

Fire Resistance: This test was conducted according to ASTM Standards [ASTM E119] to examine the concrete's ability to hinder the progression of fire from one surface of concrete to the other. One side of the specimen of size 300mmx300mmx120mm was subjected to specific temperatures. Temperature sensors were placed on the other side of the concrete specimen, measuring the temperature every 5 minutes for the duration of two hours.

Modulus of Elasticity: This test was done according to ASTM Standards [ASTM C580] to determine the modulus of elasticity by obtaining the stress versus strain curves for the samples. The specimen was subjected to a uniform load until fracture. With the generated load-deflection data from the MTS machine, the stress-strain curve was drawn for each specimen.

Infiltration Test: This test was done according to ASTM Standards [ASTM C1701] to assess the samples' potential as pervious concrete. Time is monitored to determine how long it takes for a known quantity of water to infiltrate through the concrete.

3 RESULTS AND DISCUSSION:

3.1 Fresh Concrete Tests:

3.1.1 Slump Test

In comparing the results obtained for the slump test, shown in Table 2, for the EVA concrete samples with the control sample, the results suggest that the incorporation of EVA in concrete decreases the value of slump. However, in analyzing each mix's workability, the lighter nature of the EVA aggregates compared to the conventional aggregates must be taken into consideration.

Table 2: Slump Test Results for Fresh Concrete Mixes

EVA Aggregate Size (mm)	Replacement Percentage (%)	Slump (mm)
Control	0	45
9.5	5	20
	10	10

EVA Aggregate Size (mm)	Replacement Percentage (%)	Slump (mm)
	15	30
	20	10
19	5	5
	10	20
	15	0
	20	0
38	5	15
	10	25

3.1.2 Air Content

When assessing the effect that the incorporation of EVA aggregates has on the air content of the concrete, the data proposes that there is a level of air entrapment associated with the replacement of the conventional aggregates with the EVA aggregates. In addition, there seems to be an increase in the air content associated with the increase in replacement percentage, as demonstrated in Table 3. The highest air content was that of the 20% replacement mix.

Table 3: The results of the Air Content test

EVA Aggregate Size (mm)	Replacement Percentage (%)	Air Content (%)
Control	0	3.4
9.5	5	4.5
	10	7.0
	15	9.0
	20	9.5
19	5	4.3
	10	7.9
	15	7.0
	20	8.5
38	5	3.5
	10	3.9

3.1.3 Unit Weight:

The results of the unit weight test suggest that the increase of the EVA aggregate replacement percentage results in a decrease in the unit weight of the concrete. Similarly, an increase in the EVA aggregate size seems to contribute to the decrease in unit weight as displayed in Table 4. To conclude, the mix with the lowest unit weight was found to be the one associated with the 19 mm size with a 20% replacement.

Table 4: Unit Weight Test Results for Fresh Concrete Mixes

EVA Aggregate Size (mm)	Mix Replacement Percentage (%)	Unit Weight (Kg/m^3)
Control	0	2344
9.5	5	2136
	10	1933
	15	1706
	20	1504
19	5	2019
	10	1756
	15	1474
	20	1393

EVA Aggregate Size (mm)	Mix Replacement Percentage (%)	Unit Weight (Kg/m^3)
38	5	2020
	10	1673

3.2 Hardened Concrete Tests:

3.2.1 Compressive Strength Test:

The results for the 7-day compressive strength shown in Figure 3 show a decrease in the compressive strength when a higher percentage of the conventional aggregate is replaced for the EVA aggregate. This can be explained by the weaker nature of the EVA aggregate when compared to the conventional one. There also seems to be a decrease associated with the increase in the EVA aggregate size.

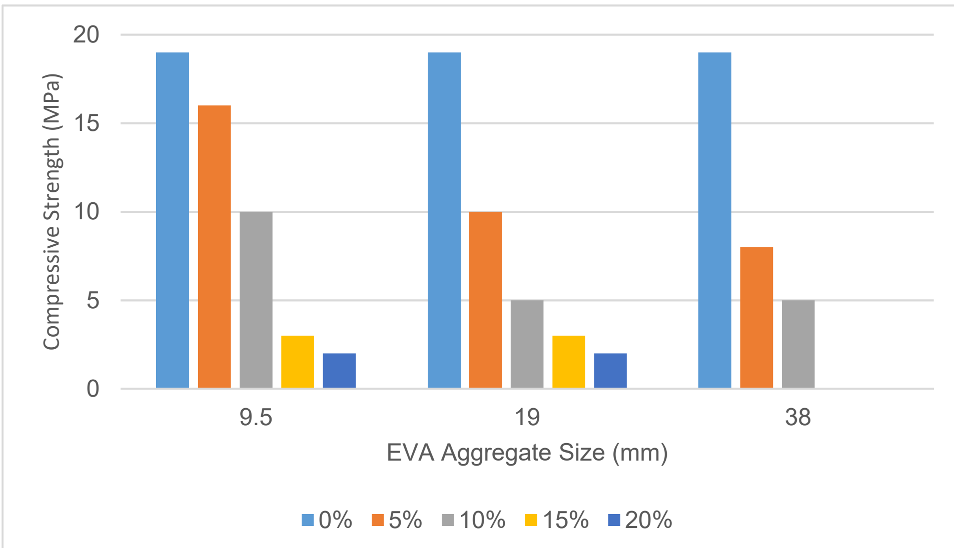

Figure 3: 7-Day Compressive Strength Results

As for the 28-day compressive strength, displayed in Figure 4, the results showed a slight improvement, moving the 9.5 mm 5% replacement mix into the starting range of structural concrete with a strength of 22 MPa. Although the results continue to show a wide gap between the strength of the control mix and the EVA concrete, the ratio of 7/28-day strength for all EVA samples is smaller than that of the control mix. Accordingly, long term testing should be conducted to study EVA concrete's potential of longer term strength gain.

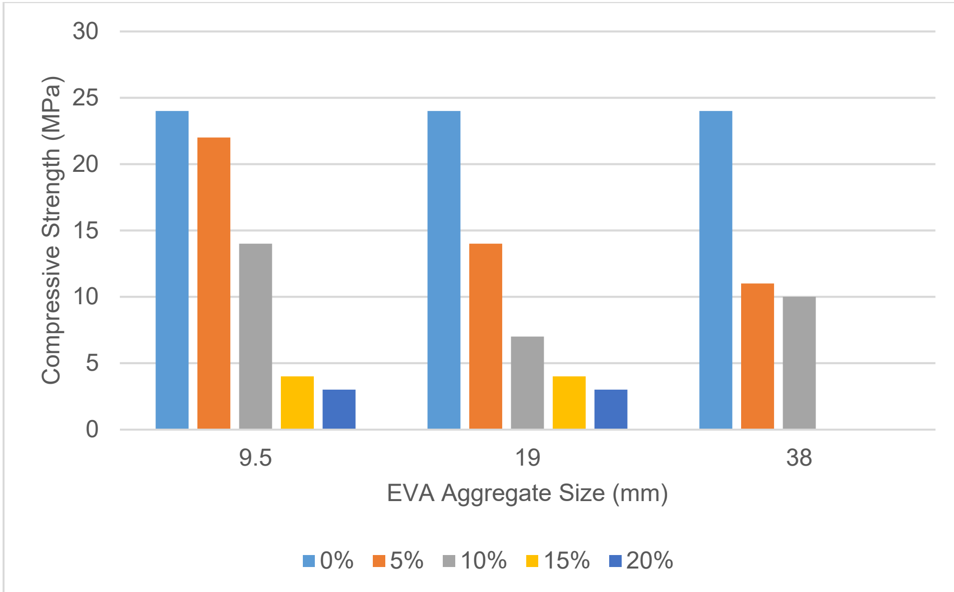

Figure 2: 28-Day Compressive Strength Results

3.2.2 Flexural Strength:

The results of the flexural strength displayed in Figure 5 suggest that the incorporation of EVA aggregates does not negatively impact the flexural strength of the concrete. In fact, there are some mixes such as the 9.5-5% and the 19-20% which yield higher values of flexural strength. The remaining mixes are all close in value to the control mix. This can be attributed to the nature of binding between the EVA aggregate particles. It can also be as a result of the EVA's high absorption, which can enhance the binding between the particles.

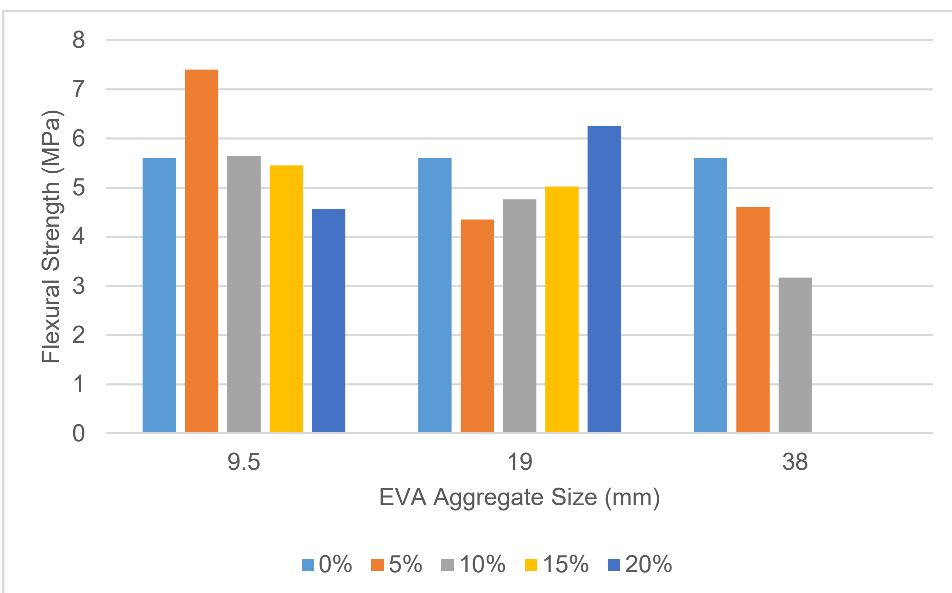

Figure 3: Flexural Strength Results

3.2.3 Abrasion:

The results of the Abrasion test, shown in Table 5, suggest that the EVA concrete has a higher abrasion resistance than the conventional concrete. This is especially true for the mixes with 10% aggregate replacement as these mixes show higher potential in abrasion resistance displayed by the lowest percentage weight loss when compared to the other mixes.

Table 5: Abrasion Test Results for Concrete Mixes

Size of EVA (mm)	Replacement Percentage (%)	Abrasion (% loss)
Control	0	6.78
9.5	5	4.42
	10	2.72
	15	3.56
	20	2.80
19	5	3.39
	10	2.00
	15	2.43
	20	2.29
38	5	3.69
	10	2.39

3.2.4 Water Penetration Test

The water penetration test results shown in Table 6 show an increase in the concrete's permeability with the increase in the EVA replacement percentage. This can be attributed to the presence of more voids in the EVA concrete when compared to the conventional concrete.

Table 6: Water Penetration Test Results for Concrete Mixes

Size of EVA (mm)	Replacement Percentage (%)	Permeability (cm)
Control	0	2.9
9.5	5	3.3
	10	4.7
	15	3.7
	20	5.3
19	5	3.6
	10	5.0
	15	**
	20	**
38	5	3.0
	10	**

** Test could not be conducted due to mixes' pervious nature.

3.3 Non-conventional Testing

3.3.1 Thermal Conductivity

The results in Table 7 demonstrate a potential for the 9.5 mm 10% replacement mix to be a good thermal insulator when compared to its conventional counterpart. This reflects a potential for higher replacement percentages to act as thermal insulators.

Table 7: Thermal Conductivity Test Results

EVA Aggregate Size (mm)	Replacement Percentage (%)	Thermal Conductivity (W m-1K-1)	Thermal Resistivity (mK W-1)
Control	0	1.26	0.79
9.5	10	1.00	1.00

3.3.2 Fire Resistance

After subjecting two samples; one control and the other with 9.5mm-10% replacement, to a specified temperature curve, the results suggest, as shown in Figure 6. that the incorporation of EVA aggregates does not affect the concrete's performance in case of fire.

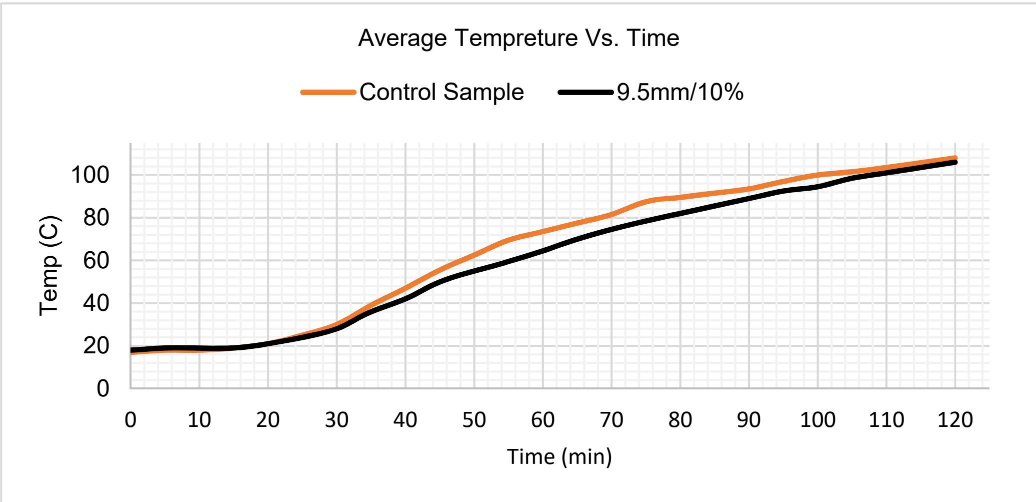

Figure 6: Fire Resistance Results

3.3.3 Modulus of Elasticity

After generating the stress-strain curves, outlined in Figure 7 for the two mixes; control and the 9.5mm-10% replacement, the results suggest that the incorporation of EVA aggregate in the concrete mix makes the concrete more ductile as opposed to its brittle nature. The EVA concrete specimen witnessed a 40% decrease in its modulus of elasticity.

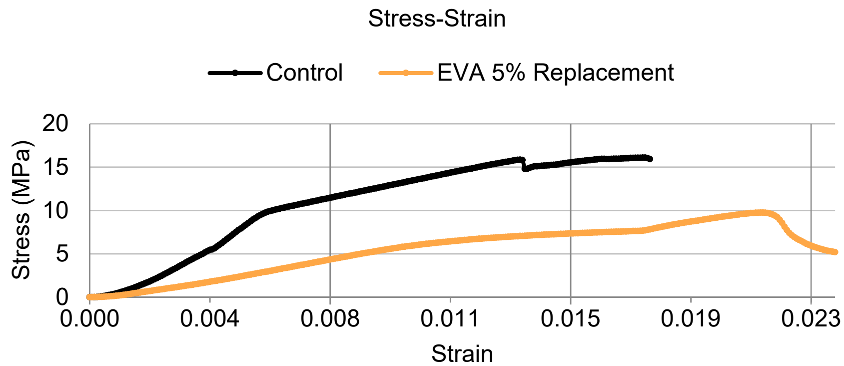

Figure 7: Stress-Strain Curves

3.3.4 Infiltration Test

The results of the infiltration test, shown in Table 8, suggest that the 19-mm size with 15% and 20% replacement show potential to be considered as pervious concrete. This was assessed in comparison to the moderate concrete infiltration rate of 8580 mm/hr. The 9.5mm-15% replacement mix's infiltration rate lies below that, eliminating it from the potential mixes to be used as pervious concrete.

Table 8: Infiltration Test Results

EVA Aggregate Size (mm)	Replacement Percentage (%)	Time to Infiltrate 1L (s)	Infiltration Rate (mm/hr)
9.5	15	170.67	4047
19	15	18.80	35660
19	20	17.47	39828

4 CONCLUSIONS

After the experimental program was carried out, the following can be concluded with regards to the incorporation of EVA foam waste in concrete:

1. EVA Concrete tends to be more abrasion resistant than conventional concrete, especially the sample incorporating 10% replacement.
2. EVA Sample with 9.5mm and 5% replacement yielded better results in terms of compressive strength.
3. Incorporation of EVA Foam in the concrete does not seem to negatively impact flexural strength.
4. EVA Concrete showed potential results in terms of fire resistance and thermal insulation.
5. When subjected to fire, EVA Concrete does not seem to release toxic fumes.
6. EVA Concrete shows encouraging potential to be used as pervious concrete.
7. EVA Concrete can be considered in non-load bearing concrete elements.

5 RECOMMENDATIONS

With these conclusions in mind, EVA concrete can be used in non-load bearing elements that can utilize its advantageous thermal insulation properties such as non-accessible roofs, shading areas, and concrete insulating shells. It can also be used as partitioning or fill concrete. Furthermore, the pervious mixes that were identified can be used in applications such as pervious pavements.
In light of the potential uncovered during the experimental work, there are various tests that should be conducted to get a more in-depth view of the EVA concrete's properties. These tests include the following list:

8. Conducting further long-term testing such as durability, mechanical properties, fatigue and creep.

9. Further test EVA concrete's potential as pervious concrete.

10. Study the interaction of admixtures with EVA in order to enhance concrete properties.

11. Investigate EVA concrete when exposed to aggressive chemical environments.

12. Conduct Modulus of Elasticity Test using strain gauge in the MTS apparatus.

13. Explore the potential of EVA Concrete in internal curing.

14. Explore the potential of incorporating EVA waste in concrete blocks.

Having opened various topics for research and shown potential for a couple of applications, EVA concrete stands as an example of how the use of waste materials in concrete can be advantageous, not necessarily in terms of mechanical properties, but other special ones. Accordingly, further research should be conducted using various types of waste materials. In addition, a mechanism for the testing of waste materials should be adopted in order to attempt to eliminate inconsistencies in the waste materials used.

Acknowledgment

This work is based primarily on the study conducted by Aleya Farhoud, Mennatallah Mansour, Radwa Shoukry, Omar El Bagoury and Shehab El Akkad as their final thesis project in the Department of Construction Engineering at The American University in Cairo.

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