The Use of Basalt Aggregates in Concrete Mixes in Jordan

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ABSTRACT

The purpose of this research is to investigate the feasibility of using basalt aggregates in concrete mixes. The researcher has designed an elaborate experimental program that included a variation of basalt percentages in concrete mixes. The laboratory investigation included measurements of compressive strength, indirect tensile strength, flexural strength, thermal conductivity, permeability, shear strength and modulus of rupture. A conventional limestone mix was used as a control mix. The results of this investigation indicate a general improvement in mix properties with the introduction of basalt aggregates in the mix.

KEYWORDS: Basalt aggregates, Concrete mixes, Jordan.

INTRODUCTION

Basalt is a hard, dense volcanic igneous rock that can be found in most countries across the globe. For many years, basalt has been used in casting processes to make tiles and slabs for architectural applications. Additionally, cast basalt liners for steel tubing exhibit very high abrasion resistance in industrial applications. In crushed form, basalt also finds use as aggregate in concrete. Crushed basalt aggregates are dense fine-grained rocks that are of very dark color- green or black and are formed when molten lava from deep in the earth's crust rises up and solidifies. Slightly coarser old sheets of basalt, now partially altered but still dark in color, are extensively quarried, crushed and sold as "traprock".

Basaltic rock in Jordan can be found in the Northeastern volcanic fields in Harrat Ash Shaam (Asi and Shalabi, 2005). Basalt is used in many countries, especially in highway and airfield pavement construction (Rodsenbaum and Skene, 1995). Jordan has also a number of quarries and crushers equipped with advanced technologies and machinery to crush basaltic rocks into construction size aggregates, and this makes them easily abundant. In conventional concrete mixes used in the construction industry in Jordan; it is customary to use limestone aggregates which are also available in great abundance. Basaltic rock aggregates are similar to limestone aggregates in many aspects. Table 1 shows key properties of limestone and basalt aggregates in Jordan. The basalt aggregates are higher in specific gravity, and lower in absorption and abrasion loss values. Based on this comparison, it is clearly obvious that basalt is likely to be suitable for use in concrete mixes and this research will investigate this matter. In order to accomplish this objective, the researcher has devised an elaborate laboratory testing program that included conventional limestone mixes with no basalt and other trial mixes containing 25%, 50%, 75% and 100% of basalt. Samples from each mix were then tested in the laboratory to determine key mix properties for the purpose of comparison.

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Table 1: Key Properties of Limestone and Basalt Aggregates Used in Jordan (Courtesy of Dr. Zuhair Samareh and Engineer Jamil Wraikat).

Aggregate Property	Basalt (Fine)	Basalt (Coarse)	Limestone (Fine)	Limestone (Coarse)
Specific Gravity (Apparent)	2.943	2.917	2.673	2.626
Specific Gravity (SSD)	2.843	2.814	2.605	2.552
Specific Gravity (Dry)	2.791	2.765	2.558	2.508
Absorption (%)	1.854	1.763	2.70	3.80
Abrasion (%)	25.9	24.4	35.0	34.8

The basalt aggregates used in this research were tested for composition at the University of Jordan by the Department of Chemistry by using the X-Ray Fluorescence (X.R.S.) test. The results of this test are summarized in Table 2.

Table 2: Chemical Composition of Basaltic Aggregates as Determined by X-Ray Fluorescence Test (X.R.S.) %.

CO_2	1.0
Na_2O	2.97
MgO	8.56
Al_2O_3	14.3
SiO_2	45.9
P_2O_5	0.372
SO_3	0.0
Cl	0.0
K_2O	0.861
CaO	11.1
TiO_2	2.25
MnO	0.174
Fe_2O_3	1.22
SrO	0.0
SUM	99.687

EXPERIMENTAL WORK

The chart in Figure 1 shows the diagram of the experimental program conducted in this investigation. Five design mixes were used including limestone reference mix, 25%, 50%, 75% and 100% basalt.

Laboratory Tests

The key properties investigated in this research project included:

1. Compressive strength as determined by breaking cube samples (15x15x15) cm. Three cubes from each mix were tested.
2. Splitting strength determined by the indirect tensile strength test. Three cylinders of 10 cm diameter by 20 cm height were tested.
3. Thermal conductivity. Three samples (30x30x5) cm were tested.
4. Permeability determined by water pressure test. Three plate samples (30x30x5) cm were tested.
5. Modulus of rupture as determined by concentrated load. Three beams (15x15x75) cm were tested.
6. Shear failure conducted by applying load at the mid point of the specimen. Three beams (20x25x110) cm were tested.
7. Flexural strength conducted under concentrated load at the mid point of the span. Three beams (20x25x310) cm were tested.

Five mixes were prepared; namely 0% basalt (as a reference mix), 25% basalt, 50% basalt, 75% basalt and 100% basalt. The composition of each mix was 40% fine aggregate passing sieve # 4 and 35% passing ½” retained on #4 sieve and 25% course aggregates passing 1” and retained on ½” sieve. In order to enhance the workability of the mix, the portion passing # 4 sieve consisted of 20% limestone sand and 20% basalt sand for all mixes.

LABORATORY RESULTS

The laboratory testing of these mixes yielded the following results:

Compressive Strength

This test was performed according to the British Standard (B.S. 1881, part 3).

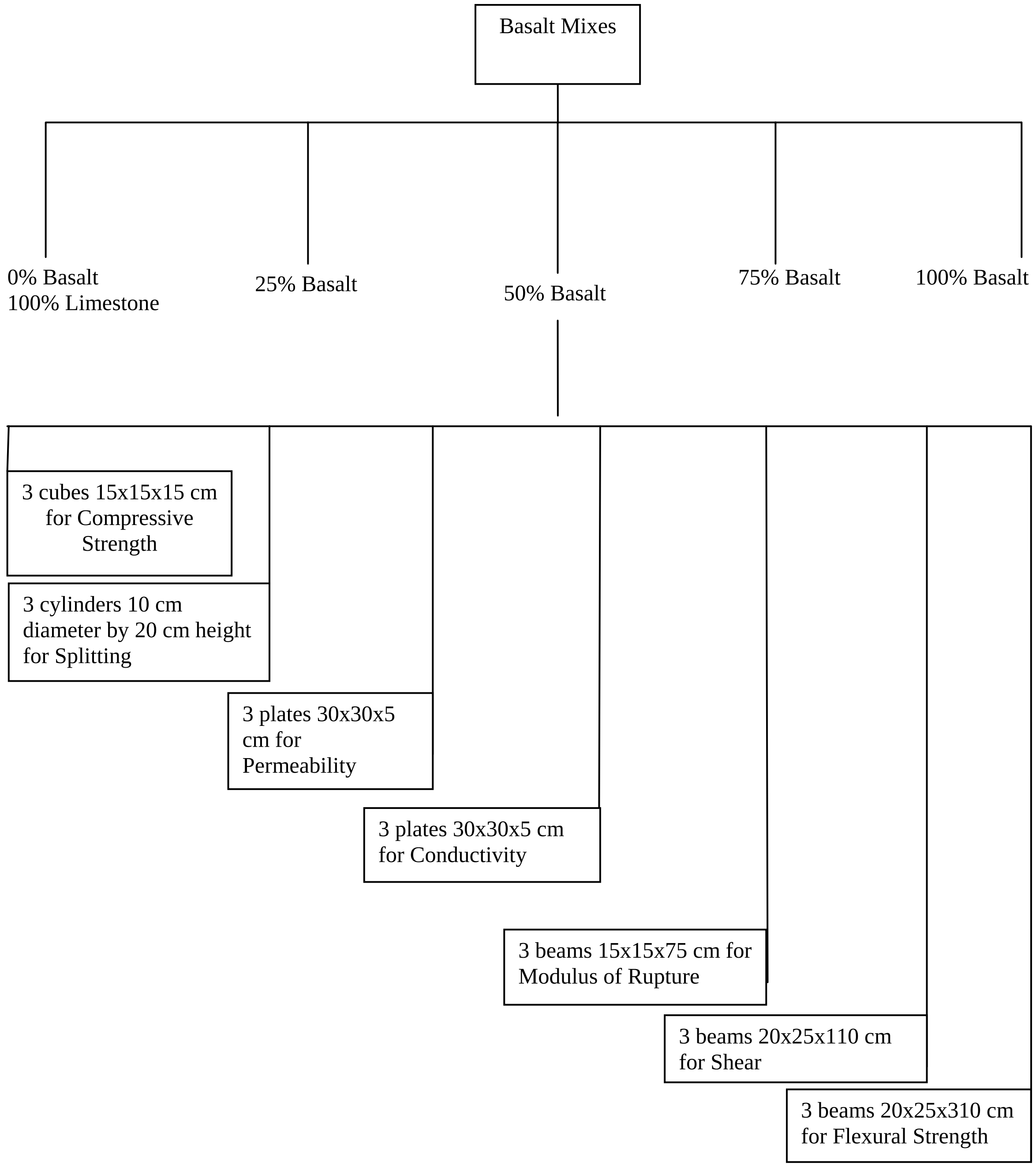

Figure (1): The Diagram of the Experimental Program Used in this Investigation.

Table 3 and Figure 2 show the results of the initial compressive strength tests that were conducted on the preliminary trial mixes containing 0%, 50% and 100% basalt, respectively. The tests were later carried out on samples from the five mixes in this research and the results are shown in Table 4 and Figure 3. In general, the compressive strength increased as the percentage of basalt in the mix is increased.

Table 3: Percentage of Basalt vs. Cube Strength (k N).

Sample No.	Failure Load (kN)	% of Basalt	Average Compressive Strength (MPa)
Sample(1)	700		
Sample(2)	735	0	31.89
1	760		
2	840	50	35.56
1	890		
2	900	100	39.78

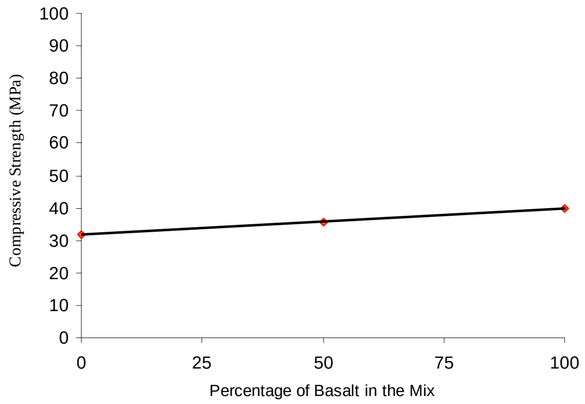

Figure (2): Results of Initial Compressive Strength Tests.

Table 4: Percentage of Basalt vs. Cube Strength (kN).

% Basalt	Failure Load (kN)	Average Compressive Strength (MPa)
0	560.5	24.91
25	635	28.22
50	792.5	35.22
75	852.5	37.89
100	925	41.11

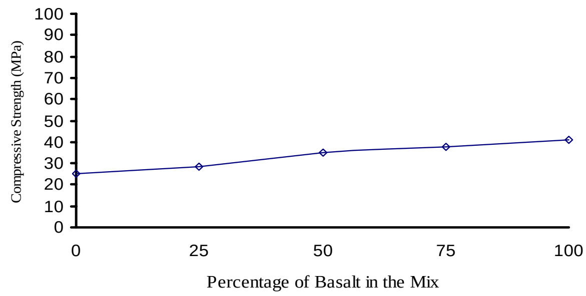

Figure (3): Percentage of Basalt vs. Cube Strength (kN).

Modulus of Rupture

The modulus of rupture tests were conducted according to ASTM C78-84.

The laboratory test results on 15x15x75 cm beams are shown in Table 5 and Figure 4 and indicate also a similar trend of increase in the modulus of rupture as the percentage of basalt in the mix increases. The results showed an increase in the modulus of rupture as the percentage of basalt in the mix increases.

Table 5: Modulus of Rupture.

%Basalt	Failure Load (kN)	Modulus of Rupture (MPa)
0	8.75	1.94
25	11.72	2.60
50	12.3	2.73
75	13.6	3.02
100	14.4	3.20

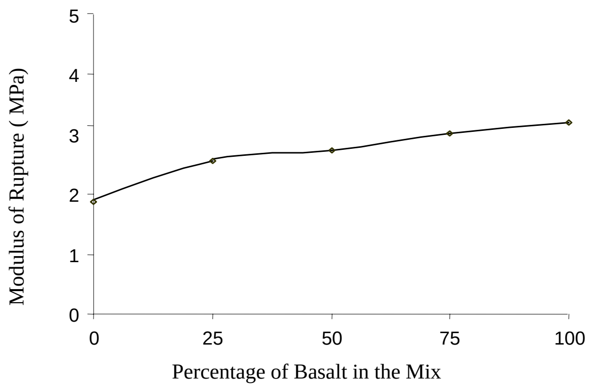

Figure (4): Modulus of Rupture Test Results.

Thermal Conductivity

The thermal conductivity of the material is the rate at which it transmits heat and is defined as the ratio of the flux of heat to the temperature gradient. Water content, density and temperature significantly influence the thermal conductivity of a specific concrete. This test was conducted according to the DIN. No. 4180. The results for limestone concrete and basalt were 1.75W/Mk and 2.3W/Mk respectively. These results were expected since the density of basalt is much higher than that of limestone with lower conductivity. Therefore, the thermal conductivity for mixes with basalt was less than that of conventional limestone concrete mixes.

The results of thermal conductivity tests show that the increase of basalt content in concrete mixes tends to reduce the conductivity below that of limestone concrete mixes. This is due to the fact that basalt mixes are denser than limestone mixes and as a result the conductivity will decrease.

Permeability

Three specimens of basalt and the same number of limestone specimens were prepared as cubes 15x15x15 cm. This test aims at finding the permeability, by exposing specimens to specified water pressures for different time periods, and then the permeability of concrete was then measured as water rises in the apparatus tubes. The concrete resistance to water depends on many factors such as aggregate type, mixing proportions, mixing condition, compaction and curing.

This test has been carried out according to the requirements of German Specification DIN. No. 1048. Test specimens shall not start before samples are 28 days of age. After preparing their exposed surfaces to water pressure, the exposed surface was subjected to a water pressure equal to 1-bar (0.1 N/mm^2) applied for 48 hours, then to a pressure of 3-bar for 24 hours and to a pressure of 7-bar for 24 hours. After completion of the test, samples were broken in middle and water penetration profiles were recorded.

The average of three tests on specimens for limestone and basalt concrete were 25mm and 18mm, respectively. This is obvious, since basalt is less permeable than limestone concrete because the density of basalt is higher than that of limestone concrete. The permeability is less than that of the normal concrete.

The test results of permeability show that the permeability is inversely proportional to the content of basalt in the mix. This was expected, since basalt is heavier than limestone. Therefore, the replacement of limestone by basalt in the mix will increase the density of the mix and will consequently reduce its permeability.

Indirect Tensile Strength

This test was conducted according to ASTM- C496-71. The indirect tensile strength was determined by splitting samples. The results are shown in Table 6 and Figure 5.

Table 6: Splitting Results and Percent Basalt.

% of Basalt	Failure Load (kN)	Tensile Strength (MPa)
0	70.0	2.23
25	81.7	2.60
50	91.0	2.90
75	109.3	3.48
100	115.0	3.60

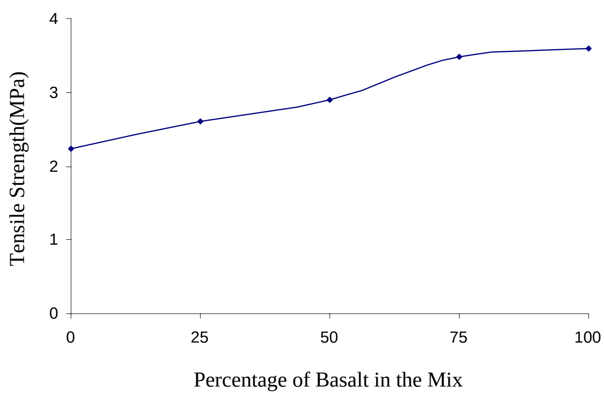

Figure (5): Results of Tensile Strength.

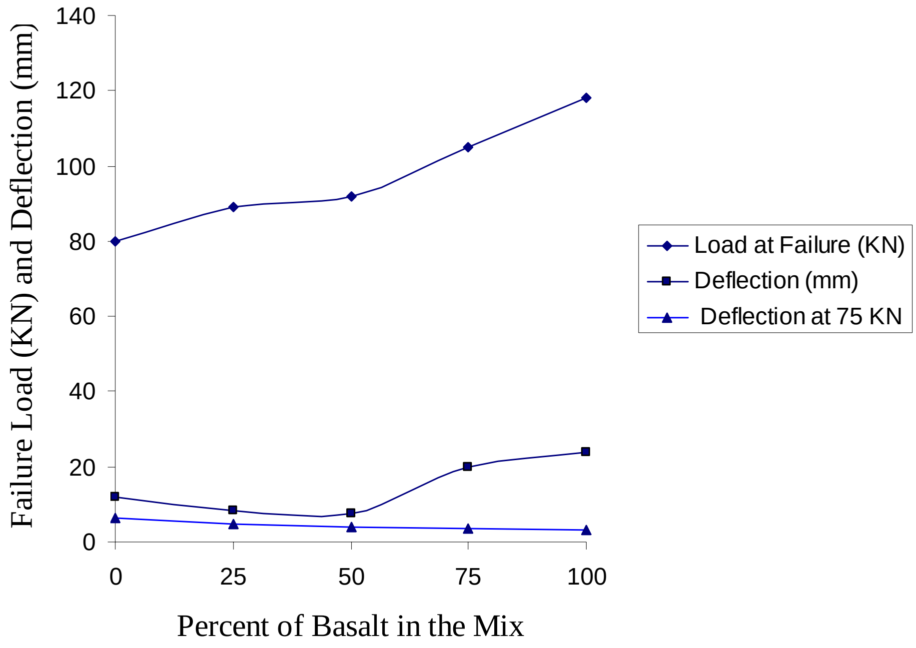

Figure (6): Load Results for Shear Failure Tests.

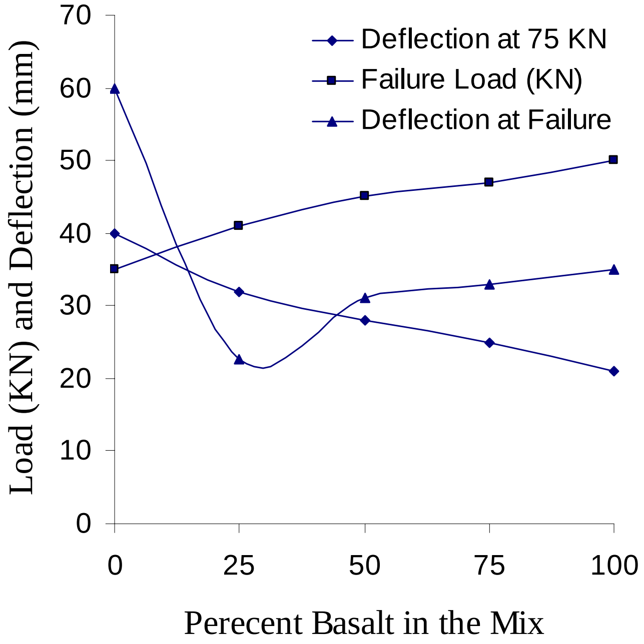

Figure (7): Results of Flexural Strength.

Shear Failure Test

The results of shear tests are shown in Table 7 and Figure 6. Deflection tends to decrease for the same load as the percentage of basalt increases. Also, it was observed that the failure load increases as well. Shear resistance increases as the percentage of basalt in the mix increases.

Table 7: Shear Stress Results (MPa) for Beam (.2x.25x1.1 m).

% Basalt	Failure Load (kN)	Deflection (mm)	Shear Stress (MPa)
0	75	6.3	0.75
0	80	12.0	0.80
25	75	4.8	0.75
25	89	8.5	0.89
50	75	4.0	0.75
50	92	7.5	0.92
75	75	3.7	0.75
75	105	20.0	1.05
100	75	3.0	0.75
100	118	24.0	1.18

Flexural Strength

The flexural strength test was done according to the ASTM, C78-84.

The trend in flexural strength variation is similar to that observed in shear strength. This is depicted clearly in Table 8 and in Figure 7. Results of the tests show that the resistance of basalt concrete to the applied load is much higher than that of limestone.

Table 8: Load (KN) vs. Deflection with Various Percentage of Basalt for Beams (.2x.25x3.1).

% of Basalt	Failure Load (kN)	Deflection (mm)	Flexural Stress (MPa)
0	30	40.0	1.20
0	35	60.0	1.40
25	30	32.0	1.20
25	41	22.7	1.64
50	30	28.0	1.20
50	45	31.0	1.80
75	30	25.0	1.20
75	47	33.0	1.88
100	30	21.0	1.20
100	50	35.0	2.00

It was noticed from the results that the permeability for basalt was 28% less than that of limestone and the thermal conductivity is also lower by 31% for mixes with basalt. Modulus of rupture, compressive strength and flexural strength were 65% higher for basalt, while splitting was 61% higher and shear resistance 57% higher for basalt concrete.

CONCLUSIONS

The laboratory test results in compressive strength, tensile strength and modulus of rupture seem to indicate that the increase in basalt percentage enhances the mix strength over the conventional limestone mix. This is due to the fact that basalt is denser and more durable and less water absorbing than limestone. Tests results also show an improvement in permeability and thermal conductivity with the increase in basalt aggregate content. In general, it is clear that the increase in basalt content in the concrete mix tends to enhance the properties of the mix.

RECOMMENDATIONS FOR FURTHER RESEARCH

The author recommends that future research incorporates performance based observations on existing elements of structures containing basalt aggregates. This can be done in a manner similar to that of this research. Also, it is observed that the deflection behavior in the laboratory testing of shear failure and flexural strength seems to indicate minimum deflection values occurring for mixes with less than 50% basalt content. To confirm this, the researcher recommends that future research conducts similar tests on mixes with basalt content below 50% in increments of 5 or 10%.

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