Comparison between Composite Beam of Limestone and Basalt Concrete

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ABSTRACT

The purpose of this study is to investigate the effect of limestone and basalt content in steel-concrete composite beams. An experimental program is set up to test the effect of basalt content on the behavior of composite beams. The properties measured in this research are the deflection of the composite beams, bonding between steel and concrete, compressive strength, flexural strength and load-strain curves for both negative and positive strain. In addition, theoretical analysis or comparison was conducted to validate experimental results. The results show significant improvement in composite beams rigidity and strength as the percentage of basalt increases in the composite beam. Deflection decreased by about 36% to 51%, bond stress increased by 28% to 63%, compressive strength increased significantly from 9% to 43% and flexural strength of the composite beam increased from 5% to 23 when the percentage of basalt was increased from 0 to 100%. The negative strain in compression in the top fiber decreased from 56% to 26% as basalt percentage was increased from 0% to 100%. However, the positive strain in tension for the bottom fiber also decreased from 43% to 17%. Validation of results through theoretical computation was conducted for comparison purposes. It was determined that composite beams were stiffer than limestone in most cases.

KEYWORDS: Composite beam, Basalt mix, Jordan, Composite basalt.

INTRODUCTION

A composite structural member is composed of two or more dissimilar materials joined together to act as a unit in which the resulting system is stronger than the sum of its parts. An example in structures is the steel-concrete composite beam in which an I or W shaped steel wide-flanged shape is filled with a concrete mix. The steel-concrete composite beam is a new composite member that economically can achieve constructability by filling the empty space in the steel H-flange with concrete. Composite beams are constructed with a rolled or built-up steel section. The resulting members are able to support significantly higher loads than reinforced concrete beams of the same sizes.

Lapko et al. (2004) conducted experimental and numerical analysis of flexural composite beams. The beams were made of two concrete layers made of normal concrete as a bottom layer and high performance concrete of basalt (HPC) as a top layer to strengthen the composite beam.

Basaltic rock in Jordan can be found in the northeastern volcanic fields in Harrat Ash Shaam (Asi and Shalabi, 2005). Basalt is normally used in highway and airfields' pavement construction (Rodsenbaum and Skene, 1995). In Jordan, many quarries and crushers are equipped with advanced technologies and machinery to crush basaltic rocks into construction size aggregates.

Accepted for Publication on 15/7/2009.

The research performed by Tan Kiang Hwee and Zhou Yu Qian (2008) included tests carried out on tensile, bond and beam specimens subjected to elevated temperatures. The researchers observed the specimens at elevated temperatures above 200ºC. The tensile and bond properties of composite beam made of basalt fiber reinforced polymer system as well as flexural stiffness and strength of beam were decreased. When the temperature exceeded 500ºC, the system was totally damaged. The modulus of elasticity of the system was not affected by the increase of temperature up to 500ºC. When the temperature exceeded 500ºC, the modulus of elasticity deteriorated rapidly.

Qiang Liu et al. conducted a study on the tolerance of basalt-fiber-reinforced polymer composites to salt water immersion, moisture absorption, temperature and moisture cycling. Parallel tests were conducted for the corresponding glass-reinforced polymer composites. It was noted that aging for 240 days in salt water or water decreased the Young's modulus and tensile strength of basalt composites slightly but significantly. Meanwhile, freeze-thaw cycling up to 199 cycles did not change the shear strength significantly, but aging in hot (40°C) salt water or water decreased the shear strength of basalt composites. The aging results indicate that the interfacial region in basalt composites may be more vulnerable to damage than that in glass composites.

Yasar Ergul et al. (2003) conducted a laboratory test to design a Structural Light-Weight Concrete (SLWC) made with basaltic pumice (scoria) as aggregate and fly ash as mineral admixtures. A control lightweight concrete mixture made with lightweight basaltic pumice (scoria) containing only Normal Portland Cement (NPC) and with fly ash lightweight concrete mixture containing 20% of fly ash as a replacement of the cement on weight basis was prepared. Fly ash is used for economical and environmental concerns. The concrete samples were cured at 65% relative humidity at a temperature of 20°C. The compressive and flexural tensile strengths of hardened concrete, the properties of fresh concrete including density and slump workability were measured. Laboratory compressive and tensile strength test results showed that SLWC can be produced by the use of scoria. However, the use of fly ash seems to be necessary for the production of cheaper and environment-friendly SLWC with the compressive and tensile strengths similar to control SLWC containing only NPC (Yasar Ergul et al., 2003).

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. 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 (Al-Baijat, 2008).

Theoretical analysis was conducted to validate results from tests conducted in the laboratory. Significant increases in compressive strength, bond stresses and flexural strength were found. However, deflection and both negative and positive strain were decreased. The calculated capacity for composite beams in terms of load carrying capacity was greater than the results obtained in the laboratory by about 20%. This result is highly influenced by the absence of stirrups and studs along the steel composite beam. This result was noted during the testing of the composite beams.

Experimental Program

The researcher has devised an elaborate laboratory testing program that included conventional limestone composite beams with no basalt and other composite beams containing 25%, 50%, 75% and 100% basalt. The dimensions of steel beam were: 152 mm flange, 300 mm deep, 3000 mm long.

The author conducted laboratory tests on 18 beams. The chart in Figure (1) shows the diagram of experimental work in this study. Five design mixes were used including limestone as base mix, 25%, 50%, 75%, 100% basalt, in-addition to three steel beams. The three steel beams and other three limestone composite beams were used as reference for comparison with four basalt mix percentages of a total of twelve beams. This constitutes a total of fifteen basalt beams with 0%,25%,50%,75% and 100%, three beams for each percentage.

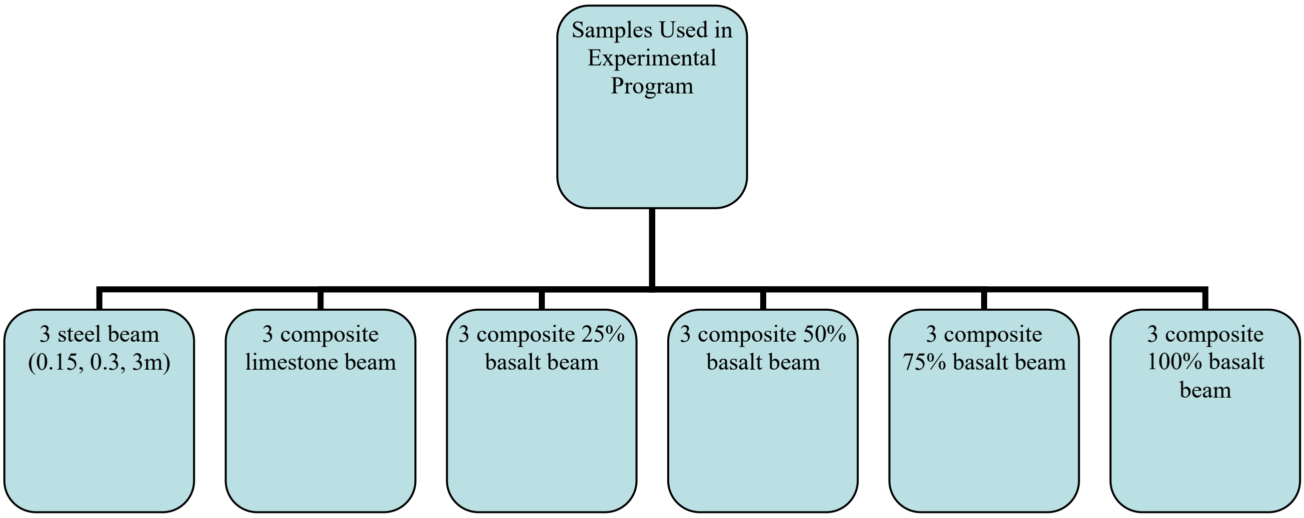


Figure (1): The chart of the experimental work used in this study.

Figure (1) shows the eighteen beams used in the experimental investigation including the variation of basalt percentages in the mixes.

Typical cross-section of the composite beam is shown in Figure (2).

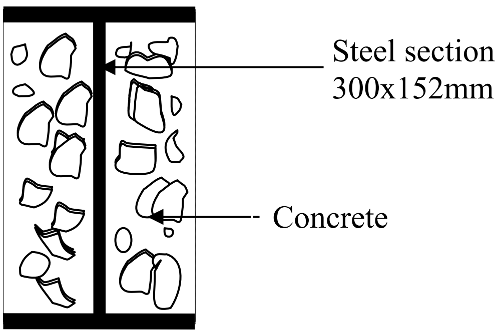


Figure (2): Composite cross-section of the beam.

Laboratory Procedure

The investigated properties in this study included:

1. Aggregate properties of basalt and limestone.
2. Deflection of steel, limestone and basalt composite beams. Eighteen samples (3000x300x152) mm were tested.
3. Bonding between steel and basalt concrete. Three samples for each mix were tested; (150x150x150)mm cube with 16mm steel bar embedded at the center of the cube.
4. Compressive strength is usually measured by the load required to break a cube (150x150x150) mm sample that has been cured for 28 days. Fifteen cubes were tested for this research, three cubes for each mix.
5. Flexural strength test was conducted on concentrated load at the mid of the span length.
6. Stress-strain curve was obtained by measuring the stress and strain along the depth of the beam using Demic gage at three levels of the cross-section of the beam at the top, the middle and the bottom fiber.
7. Theoretical analysis was conducted to compare the results with those obtained at the laboratory.

The composition of each mix is shown in Table (1).

In order to maintain the workability of the mix, the fine aggregate consisted of 20% limestone sand and 20% basalt sand for all mixes, except limestone mix (0% basalt).

The water cement ratio is 0.7 including 0.25 for hydration, and the cement is 350 kg per cubic meter of concrete.

Table (1): Percentage of basalt in composite section in each mix.

Sieve no.	Limestone 0% basalt	25% basalt		50% basalt		75% basalt		100% basalt
Passing no. 4 (Fine) sand basalt sand	40 0	20 20		20 20		20 20		20 20
Passing 3/8 retained on no.4 medium	30	7.5[a]	22.5[b]	15[a]	15[b]	22.5[a]	7.5[b]	30[a]
Passing 1" retained on 3/8 coarse	30	7.5[a]	22.5[b]	15[a]	15[b]	22.5[a]	7.5[b]	30[a]
Total	100	100		100		100		100

[a] Percentage of basalt aggregate in the mix.

[b] Percentage of limestone.

Table (2): Key properties of limestone and basalt aggregates used in Jordan (Courtesy of Dr. Zuhair Samareh and Engineer Jamil Wraikat) (Al-Baijat, 2008).

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

LABORATORY RESULTS AND DISCUSSION

The experimental study of these tests yielded the following results:

Properties of Basalt and Limestone Aggregate

Specific gravity in addition to absorption and abrasion were tested for both limestone and basalt. Table (2) shows the properties of basalt and limestone in Jordan. The coarse and fine aggregates were tested according to ASTM C127 and C128, respectively, while the abrasion test was conducted based on ASTM C131 and AASHTO T96.

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 and the corresponding chemical composition for basalt aggregates are summarized in Table (3).

Deflection

The composite beams were subjected to the concentrated load at the middle of the span according to ACI Code 9-5. The total number of beams tested was 18 beams; three steel and three limestone beams, in addition to 12 beams for different percentages of basalt. The deflection of the set of the composite beams is shown in Figure (3).

Table (3): Chemical composition of basaltic aggregates as determined by X-ray fluorescence test (X.R.S.)% (Al-Baijat, 2008).

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

The laboratory results of the deflection tests indicate that the basalt composite beams are stiffer than the limestone ones, as the percentage of basalt increased from 0% to 100%. This was associated by a decrease in the deflection in the range of 36% to 47%. From theoretical calculation of the deflection, it was noted that the capacity of the composite beam was higher than the value resulting from the laboratory tests. The calculated deflections were 60, 55, 51, 49 and 39mm for 0%,25%,50%,75% and 100%, respectively. This result was due to the absence of stirrups or studs in the section.

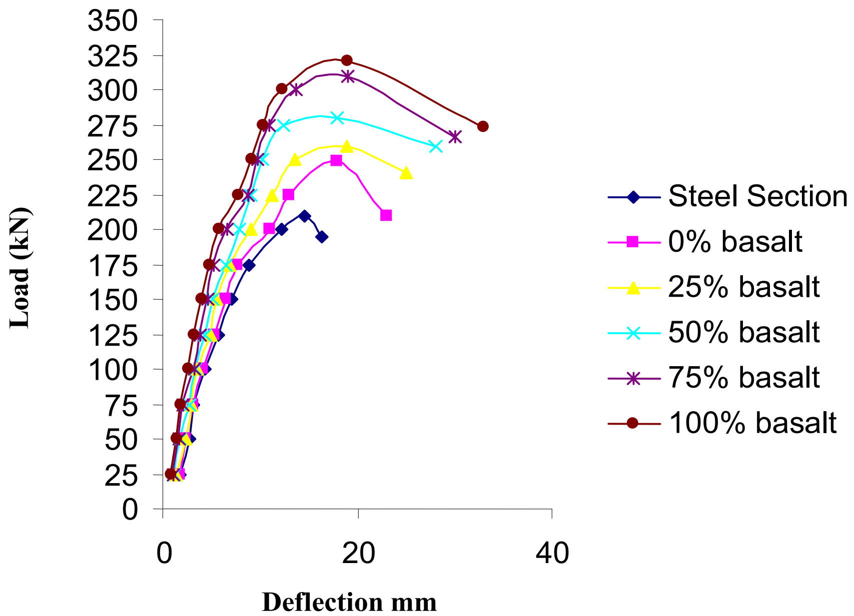


Figure (3): Load (kN) vs. Deflection mm for Various Percentage of Basalt

Bond between the Reinforcement and Basalt Concrete

The specimen used in bond push-out test is the 150x150x150mm cube with 16 mm deformed steel bar placed at the center of the cube. Three cubes of each mix were tested after 28-days. Bond stress between steel and concrete is influenced by the following factors (Asi, 2005):

1. Quality of the matrix.
2. Compaction of the concrete near the steel bars.
3. Compressive strength of the concrete.
4. Surface of the steel (round or deformed).

The results of the test investigation are shown in Figure (4) and Table (4).

Table (4): Breaking load vs. bond stress.

Diameter of Steel Bar (mm)	Percentage of Basalt	Breaking Load (kN)	Bond Stress (kPa)
16	0	40	0.795
16	25	55	1.1
16	50	67	1.33
16	75	88	1.75
16	100	106	2.21

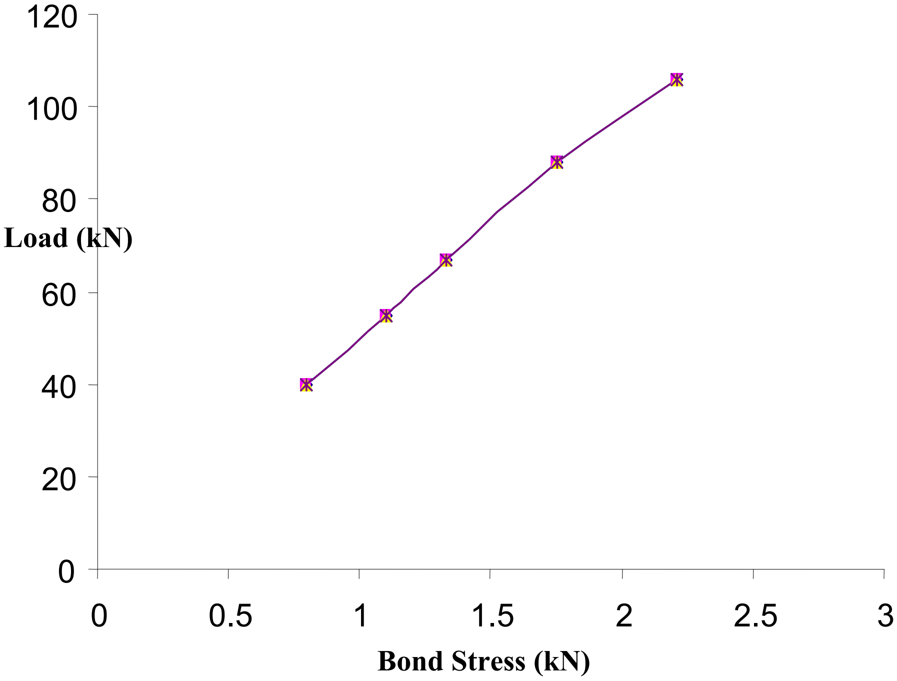


Figure (4): Breaking load vs. bond stress.

Table (5): Breaking load, percentage of basalt and compressive strength.

Breaking Load (kN)	Percentage of Basalt	Compressive Strength (MPa)
750	0	33.4
824	25	36.6
873	50	38.8
930	75	41.33
1325	100	58.9

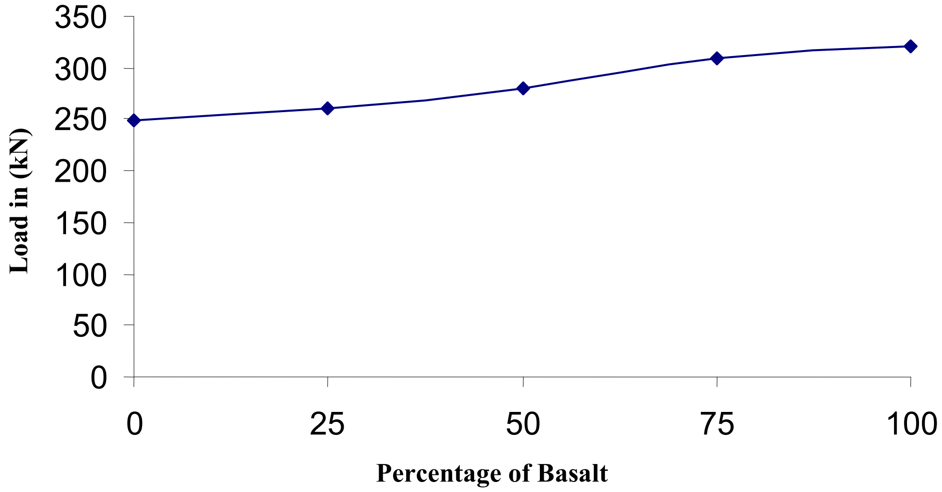
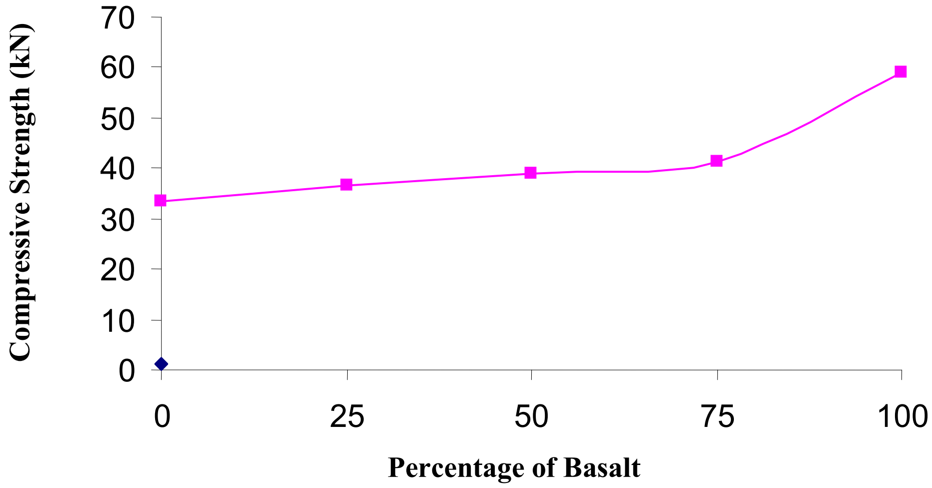


Figure (6): Failure Load (kN) vs Percentage of Basalt.



Figrure (5): Compressive Strength (kN) vs Percentage of Basalt.

Bond stress is the force per unit surface area of a reinforcing bar.

$\sigma = P/L\ (2\pi r)$

where:

σ = bond stress.

P = total load.

L = length of the embedment bar.

r = radius of the steel bar(mm).

From this experimental study, it was noted that the bond enhanced by about 28% to 63% as the percentage of basalt increased, this is due to the increase in the compressive strength as the percentage of basalt increased in the mix.

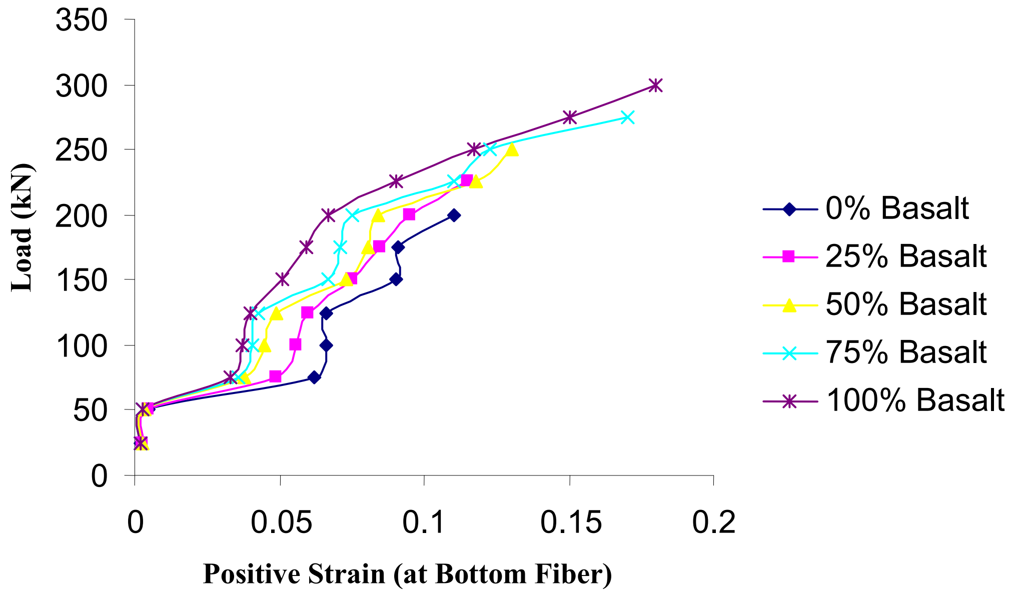


Figure (7): Load (kN) vs. Positive Strain for Various Percentage of Basalt

Compressive Strength

Compressive strength test was performed according to British Standard (B.S. 1881, Part 3) and (ASTM C39 and AASHTO T22). Table (5) and Figure (5) show the results of limestone and variation of basalt percentages. The tests were carried out on fifteen cubes, three for each percentage of basalt (0%, 25%, 50%, 75%, and 100%). The results indicated significant increases in the compressive strength as the percentage of the basalt increases in the mix. Compressive strength was increased from 9% to 43% as the percentage of basalt increased. This is due to the fact that the aggregate particles of basalt are stronger than those of limestone. The compressive strength values versus percentage of basalt were shown in Table (5) and Figure (5).

Flexural Strength

The flexural strength test was conducted according to the standard methods of (ASTM C78-84 and AASHTO T97). Five mixes were prepared; namely: limestone (0% basalt as base mix), 25%, 50%,75% and 100% basalt, in addition to the steel beam. The failure load values of the limestone and basalt beams were shown in Table (6) and Figure (6).

Table (6): Failure load vs. percentage of basalt.

Percentage of Basalt	Failure Load (kN)	Calculated Load Carrying (kN)
0	248	337
25	260	350
50	280	355
75	309	360
100	320	377

The failure load for steel beam is 210 kN.

The capacity of the composite beam increases in the case of composite basalt beam by about 5%-23% than that of limestone, as the percentage of basalt moved from 0%-100%. The calculated load was greater than that obtained by experimental results by approximately 20%. This is due to the absence of stirrups and studs along the steel beam .

Load-Strain Curve

Stress-strain curve was obtained by measuring the stress and strain along the depth of the beam using Demic gages, placed 10 cm to the left and right of the center line of the beam at three levels of the cross-section of the beam (top, middle and bottom fiber). At the beginning of the test, all these distances are the same. As the load increases, the top distance (compression) gets smaller and the bottom distance (tension) increases.

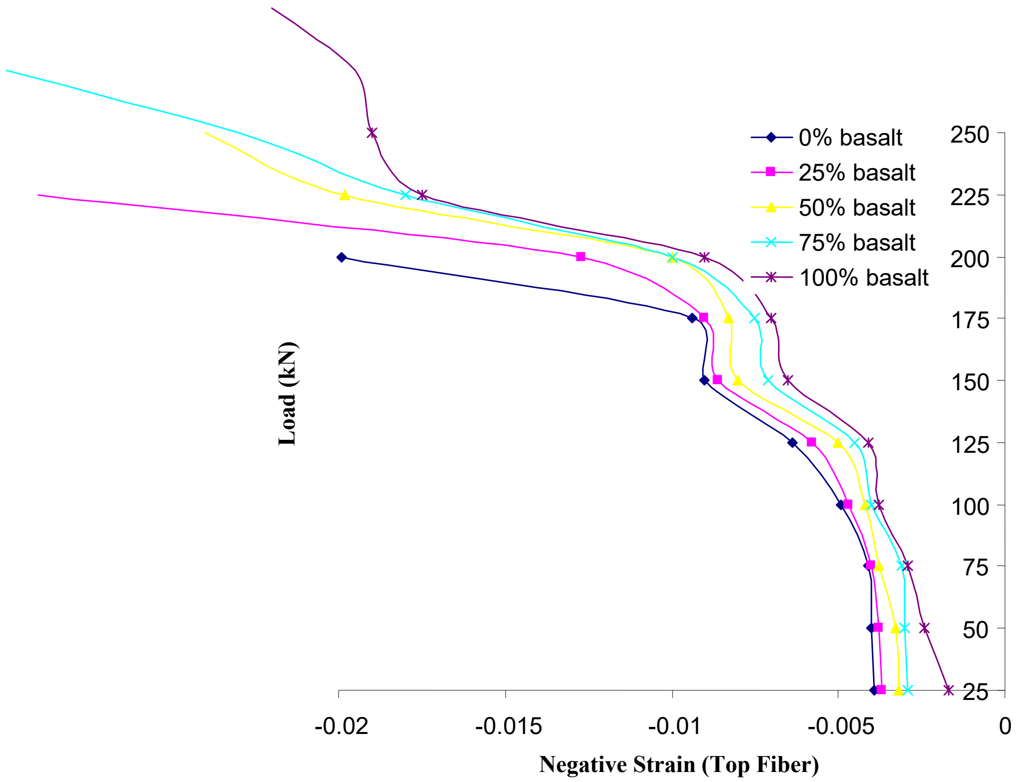


Figure (8): Load (kN) vs. Strain at The Top Fiber of The Mid Span (Compression Strain) for Various Percentage of Basalt.

Figure (7) shows the positive strain at the extreme bottom, which increases as the load increases and decreases as the percentage of basalt increases. However, the negative strain at the top fiber is shown in Figure (8). The compression strain at the top decreased as the percentage of basalt increased and increased as the load increased.

The negative strain (top fiber) decreases by about 56%-22% as the percentage of basalt increases, and also the positive strain (bottom fiber) decreases from 43%-17% as the percentage of basalt increases.

Validation of Test Results

The capacity of each composite beam was found using simple calculations. The density of concrete vs. percentage of basalt is shown in Table (7).

Table (7): Theoretical capacity of composite beams.

Percentage of Basalt, %	Density of Concrete, kg/m^3
0	2200
25	2250
50	2310
75	2360
100	2400

Table (8): Key properties of the composite section.

% of basalt	**Modular ratio (n)**	**I_{comp} mm^4**	**Width of Transform Web Section (mm)**	**Ec MPa**	**Modulus of Section St=Sb (mm^3)**	**Moment (kN.m)**	**Calculated Load (kN)**	**Lab Load (kN)**
0	8.1	101,106,837	17.95	25642	674045	236	337	248
25	7.5	104,884,368	19.43	27767	699229	245	350	260
50	7	106,437,156	20.8	29742	709554	249	355	280
75	6.75	107,887,505	21.55	30713	719250	252	360	309
100	6	112,987,172	24.25	38625	753247	264	377	320

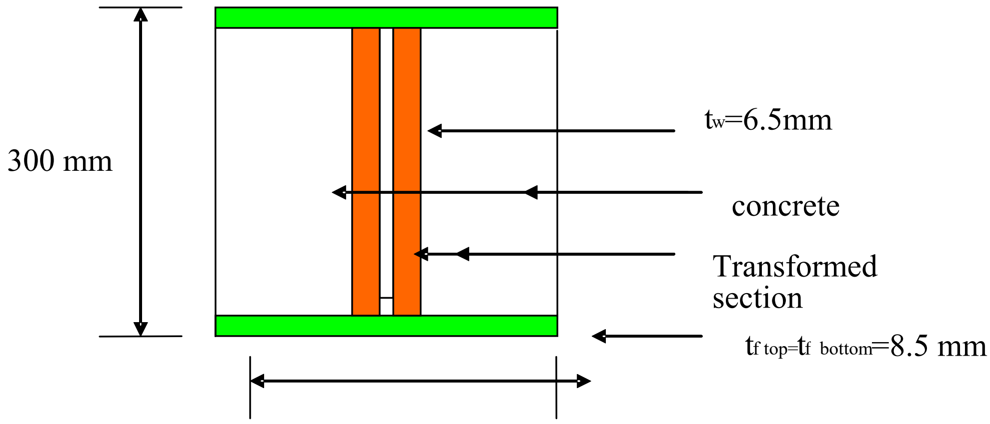


Figure (9): The transform web section of the composite beam.

The density of composite beams increased from 0.025%-0.08% as the percentage of basalt increased from 0%-100%.

Modular ratio and modulus of elasticity of concrete should be calculated from:

$n= E_s/E_c$

and

$E_c= w^{1.5}(0.043)\ (f_c)^{0.5}$ (SI)

where:

n=modular ratio

E_s=modulus of elasticity of steel

E_c=modulus of elasticity of concrete

w=weight of concrete

f_c = compressive strength of concrete

The transformed section of concrete will be obtained from:

$b_{effective}=b_{flange} - b_{web}$

$h_{effective}=(h-2t_f)$

$I_{tr}=(b_{effective}\ h^3_{effective} /12)$

$I_{steel}= (bh^3/12)_{web}+2(bh^3/12)_{flange}$

$I_{com}= I_{steel} + I_{tr}$

M= Fy(S)

M=PL/4

P=4M/L

The properties are shown in Table (8).

The analytical validation of results shows that the results obtained in the laboratory tests are comparable with the calculated values as shown in Table (8).

The transformed section is shown in Figure (9).

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

The laboratory test results related to compressive strength seem to indicate that the increase in basalt percentage enhances the mix strength over the conventional limestone mix, which in turn increases the load carrying capacity of the composite beam. This is due to the fact that basalt is denser, more durable and less water absorbing than limestone. The laboratory results indicate that bond stresses improve significantly as the percentage of basalt increases. In addition to that, the capacity of the beam increases, while deflection decreases as the percentage of basalt increases. This is due to the fact that the beam is stiffer for the 100% basalt beam when compared to 0% basalt (limestone). Bond stress increases as the percentage of basalt increases. However, deflection decreases as the percentage of basalt increases. Flexural strength increases as the percentage of basalt increases about 30%. Also, strain decreases for both cases of positive and negative strain as the percentage increases and increases when the load increases.

It was also noted that the failure loads in most cases were less than the capacity of the section. This is due to the absence of studs and stirrups along the web of the steel section. The author recommends further study on composite columns and recommends contractors strongly to use the composite beam structure. Studs and stirrups should be provided and investigated in the future study.

Even though the research proved that basalt improves the strength and stiffness of concrete, it is highly recommended that future investigations are carried out on the long term performance before recommending this type of concrete. Previous researchers (Goguel and Milestone, 1997; Shayan and Morris, 1997) showed that some basalts exhibit potential for alkali release and may result in Alkali-Aggregate Reaction (AAR). This reaction may result in degradation of concrete and affect adversely the durability of concrete and structures.

ACKNOWLEDGEMENTS

The researcher would like to acknowledge the valuable assistance of Professor Sultan Abu-Orabi, the President of the University of Tafila, for his continuous support of this research project, and the financial assistance of the University of Tafila was exemplary and vital for the completion of this research project. The author would also like to acknowledge the assistance of his colleagues Dr. Subhi Bazlamit and Dr. Amin Al-Massri for their valuable assistance in this project.

The author is also grateful for Dr. Saleh Al-Jefout, Dean of Graduate Studies for his contribution to this research project. Encouragement and financial support were very essential throughout this research project. The author also wishes to express his gratitude to Professor Abdul-Qader Al-Najmi, Chair Person of the Civil Engineering Department at the University of Jordan for his valuable assistance toward the testing of the most specimens at the Department's laboratories.

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