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A STUDY ON PARTIAL REPLACEMENT OF COARSE AGGREGATE WITH BASALT AGGREGATE IN HIGH STRENGTH CONCRETE

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ABSTRACT

Concrete technology has been changing rapidly and constantly since its discovery. The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete Of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. The scope of this work is limited to the development of a suitable mix design to satisfy the requirements of workability and strength of the concrete mix using basalt aggregate as a coarse aggregate. To evaluate the workability of concrete mixes using basalt aggregate as coarse aggregate. To evaluate the strength of hardened concrete using basalt aggregate as coarse aggregate The results of the compressive strength tests will be conducted on the trial mixes containing 0%,25%, 50%,75% and 100% basalt, respectively. The compressive strength will be tested as the percentage of basalt content in the mix is increased. Five mixes were prepared; namely 0% basalt (as a control mix), 25% basalt, 50% basalt, 75% basalt and 100% basalt for each set of design mix. The composition of each mix was 60% coarse aggregate of 20 mm size and 40%coarse aggregate of 10mm size. Fine aggregate confines to zone-I.

I. INTRODUCTION

1.1 GENERAL

Concrete is the most commonly used material in various types of construction, from the flooring of a hut to a multi storied high rise structure from pathway to an airport runway, from an underground tunnel and deep sea platform to high-rise chimneys and TV Towers. In the last millennium concrete has demanding requirements both in terms of technical performance and economy while greatly varying from architectural masterpieces to the simplest of utilities. It is difficult to point out another material of construction which is as versatile as concrete.

Concrete is one of the versatile heterogeneous materials, civil engineering has ever known. With the advent of concrete civil engineering has touched highest peak of technology. Concrete is a material with which any shape can be cast and with any strength. It is the material of choice where strength, performance, durability, impermeability, fire resistance and abrasion resistance are required. It is well recognized that coarse aggregate plays an important role in concrete.

Coarse aggregate typically occupies over one-third of the volume of concrete, and research indicates that changes in coarse aggregate can change the strength and fracture properties of concrete. To predict the behavior of concrete under general loading requires an understanding of the effects of aggregate type, aggregate size, and aggregate content. This understanding can only be gained through extensive testing and observation.

There is strong evidence that aggregate type is a factor in the strength of concrete. Ezeldin and Aitcin (1991) compared concretes with the same mix proportions containing four different coarse aggregate types. They concluded that, in high-strength concretes, higher strength coarse aggregates typically yield higher compressive strengths, while in normal-strength concretes; coarse aggregate strength has little effect on compressive strength. Other research has compared the effects of limestone and basalt on the compressive strength of high-strength concrete (Giaccio,Rocco, Violini, Zappitelli, and Zerbino 1992). In concretes containing basalt,load induced cracks developed primarily at the matrix-aggregate interface, while in concretes containing limestone; nearly all of the coarse aggregate particles were fractured. Darwin, Tholen, Idun, and Zuo (1995, 1996) observed that concretes containing basalt coarse aggregate exhibited higher bond strengths with reinforcing steel than concretes containing lime stone. There is much controversy concerning the effects of coarse aggregate size on concrete, principally about the effects on fracture energy.

Some research (Strange and Bryant 1979, Nallathambi, Karihaloo, and Heaton 1984) has shown that there is an increase in fracture toughness with an increase in aggregate size. However, Gettu and Shah (1994) have stated that, in some high-strength concretes where the coarse aggregates rupture during fracture, size is not expected to influence the fracture\2parameters.Tests by Zhou, Barr, and Lydon (1995) show that compressive strength increases with an increase in coarse aggregate size. However, most other studiesdisagree. Walker and Bloem (1960) and Bloem and Gaynor (1963) concluded that an increase in aggregate size results in a decrease in the compressive strength of concrete. Cook (1989) showed that, for compressive strengths in excess of 69MPa (10,000 psi),smaller sized coarse aggregate produces higher strengths for a given water-cement ratio. In fact, it is generally agreed that, although larger coarse aggregates can be used to make high-strength concrete, it is easier to do so with coarse aggregates below 12.5 mm (Y, in.) (ACI 363-95).There has not been much research on the effects of coarse aggregate content on the fracture energy of concrete.

One study, conducted by Moavenzadeh and Kuguel (1969), found that fracture energy increases with the increase in coarse aggregate content. Since cracks must travel around the coarse aggregate particles, the area of the crack surface increases, thus increasing the energy demand for crack propagation. There is controversy, however, on the effects of coarse aggregate content on the compressive strength of concrete. Ruiz (1966) found that the compressive strength of concrete increases with an increase in coarse aggregate content until a critical volume is reached, while Bayasi and Zhou (1993) found little correlation between compressive strength and coarse aggregate content. In light of the controversy, this report describes work that is aimed at improving the understanding of the role that coarse aggregate plays in the compressive, tensile, and fracture behaviors of concrete.

Concrete technology has been changing rapidly and constantly since its discovery. The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. Though it is based on sound technical principles and heuristics, the entire process is not in the realm of science and precise mathematical calculations. This is because of impreciseness, vagueness, approximations and tolerances involved. The objective of any mix design method is to determine an appropriate and economical combination of concrete ingredients that can be used for a first trial batch to produce a certain concrete which is close to that can achieve a good balance between various desired properties of concrete at the minimum cost.

A mixture proportioning only provides a starting mix design that will have to be more or less modified to meet the desired concrete characteristics. In spite of the fact that mix design is still something of an art, it is unquestionable that some essential scientific principles can be used as a basis for calculations. Production of concrete and utilization of concrete has rapidly increased, which results in increased consumption of natural aggregate as the largest concrete component. It is well recognized that coarse aggregate plays an important role in concrete. Coarse aggregate typically occupies over one-third of the volume of concrete, and research indicates that changes in coarse aggregate can change the strength and fracture properties of concrete. To predict the behavior of concrete under general loading requires an understanding of the effects of aggregate type, aggregate size, and aggregate content. This understanding can only be gained through extensive testing and observation. It is customary to use limestone aggregates which are also available in great abundance.

1.2 BACKGROUND

In modern concrete technology, adding other type aggregate to cement is a well-established practice. Other type aggregate are added to concrete for various purposes such as:

• Improving compressive strengths at early ages

• Increasing durability of hardened concrete

• Enhancing mechanical properties of concrete

• Producing greener concrete for environmental sustainability

Recent development, basalt is a hard, dense volcanic igneous rock that canbe found in most countries across the globe. For manyyears, basalt has been used in casting processes to maketiles and slabs for architectural applications. Additionally,cast basalt liners for steel tubing exhibit very highabrasion resistance in industrial applications.

In crushedform, basalt also finds use as aggregate in concrete.Crushed basalt aggregates are dense fine-grained rocksthat are of very dark color- green or black and are formedwhen molten lava from deep in the earth's crust rises upand solidifies. Slightly coarser old sheets of basalt, nowpartially altered but still dark in color, are extensively quarried, crushed and sold as "trap rock".

Basaltic rock in Jordan can be found in theNortheastern volcanic fields in Harrat Ash Shaam (Asiand Shalabi, 2005). Basalt is used in many countries,especially in highway and airfield pavement construction(Rodsenbaum and Skene, 1995). Jordan has also anumber of quarries and crushers equipped with advancedTechnologies and machinery to crush basaltic rocks intoconstruction size aggregates, and this makes them easilyabundant. In conventional concrete mixes used in theconstruction industry in Jordan; it is customary to uselimestone aggregates which are also available in greatabundance. Basaltic rock aggregates are similar tolimestone aggregates in many aspects. Table 1 shows keyProperties of limestone and basalt aggregates in Jordan.

The basalt aggregates are higher in specific gravity, andlower in absorption and abrasion loss values. Based onthis comparison, it is clearly obvious that basalt is likelyto be suitable for use in concrete mixes and this researchwill investigate this matter. This report describes work that is aimed at improving the understanding of the role of aggregates in concrete. The variables considered are aggregate type, aggregate size, and aggregate content in normal and high-strength concretes. Compression,flexural, and fracture tests are used to better understand the effects aggregates have in concrete.

1.3 SCOPE

The scope of this work is limited to the development of a suitable mix design to satisfy the requirements of workability and strength of the concrete mix using basalt aggregate as a coarse aggregate.

 Percentage of the basalt aggregate used are 0%, 25% and 50 %, 75%,100 of the concrete mixes.

Properties of concretes and test methods are as follows for M50,M60 Grades:

 Compressive Strengths of concrete at 0, 3, 7, 28, 56 days

 Tensile Strength of concrete at 28 days

1.4 OBJECTIVES:

1. To evaluate the workability of concrete mixes using basalt aggregate as coarse aggregate.

2. To evaluate the strength of hardened concrete using basalt aggregate as coarse aggregate

II. LITERATURE REVIEW

Aggregate is the part of mineral materials and crushed stone that is used in the main part of pavement construction (it is about 92 to 96 percent from Hot-Mix Asphalt (HMA) and in base and sub base layers). In Jordan, there are two main types of aggregate (limestone in the Northern part and basalt in the southeastern part) and each type have distinguished properties that make them good in preventing some pavement distresses different from the other. Basalt is that type of volcanic rocks, grey to black in color, contains less than 20% quartz, 10% feldspathoid and at least 65% of the feldspar of its volume. Basalt is considered an igneous rock with fine grains due to the rapid cooling of lava.

Asi et al. 2009, studied the use of basalt in asphalt concrete mixes. Their study focused on skid resistance and stripping and how to reduce them using the optimum replacement percentage of the limestone aggregate by basalt. The Marshall Mix design was used to prepare the asphalt mixes. These mixes were evaluated using Marshals stability, indirect tensile strength, stripping resistance, resilient modulus, creep, fatigue, and permanent deformation. The optimum percentage of replacement to reduce stripping and increase skid resistance while using basalt in pavement construction was found to be 1% by total weight of aggregate by adding fine materials of fly ash or hydrated lime.

Yildirm et al. 2004, studied the effect of aggregates on rutting performance. The study was a five-year research project, which was sponsored by the Texas Department of Transportation (TxDOT) to evaluate the correlation between field and laboratory performance of asphalt mixtures tested using the Hamburg Wheel Tracking Device (HWTD) and to determine the relationship between hot mix asphalt concrete (HMAC) field performance and the HWTD test results. Nine test sections were constructed on IH 20 in Harrison County. Three different mix design methodologies and three different aggregates were utilized to construct the test sections, The Super pave gyratory compactor was used to prepare the samples with 7 ± 1 percent air void level. All the tested specimens performed well and satisfied TxDOT specifications for HWTD. The rutting data obtained from test sections showed a very good trend with the HWTD test data, with the highest for rutting data collected from both techniques for mixes prepared with gravel,while mixes prepared from quartzite and sandstone showed very similar rutting at the field and lab.

Masad et al. 2003 was evaluated the aggregate characteristics affecting HMA concrete performance. The study assessed the HMA sensitivity to aggregate shape characteristics. Aggregate shape was characterized through detailed measurements of angularity, form, and texture using the Aggregate Imaging System (AIMS). The shape characteristics were presented in terms of the distribution of the property in an aggregate sample rather than an average index of this property. A viscoplastic model for permanent deformation was also developed in their study. The model accounted for the aggregate structure in the mix, which was related to the shape properties measured using AIMS.

Hanf 2000 is used sand and gravel in Super pave mixtures and aimed at finding the best blend of sand and gravel to face the challenging and changing of specifications for aggregates used in HMA considering the Super pave criteria for mix design. The Super pave mix design and Marshall Mix design were used to prepare the samples. The volumetric properties for both mix design methods for a given gradation were compared. The samples were also tested for moisture susceptibility. Findings of the study showed that if Marshall Mix met the VMA and VFA criteria, then the volumetric properties should meet the Super pave design criteria, but probably not with the same gradation. It was also found that meeting the requirements was related directly to fine aggregate angularity, restricted zone, coarse aggregate angularity, sand equivalent, dust to asphalt ratio, VMA, or VFA.

Zhou, Barr, and Lydon (1995) studied the fracture properties of concretes with compressive strengths ranging from 80 to 115MPa (11,600 to 16,700 psi). Mixtures with water- to-cementations' material ratios of0.23 and 0.32 and 10% and 15% silica fume replacements of cement (by weight) were compared. Concretes made with 10rnm (0.4 in.) gravel and 10rnm (0.4 in.) and 20rnm (0.8 in.) crushed limestone were also compared. Zhou eta!. concluded that, in contrast to other studies, increasing the coarse aggregate size from 10rnm (0.4 in.) to 20rnm (0.8 in.) increases the compressive strength of the concrete by about 10 percent. They also found that, similar to normal-strength concrete, the fracture energy of high-strength concrete increases with increasing aggregate size. However, also in contrast to other studies, they observed a decrease in fracture energy with increasing compressive strength. They concluded that the fracture energy decrease may be due to the improvement in the matrix-aggregate bond which results in cracks developing through aggregates rather than passing along the matrix-aggregate interface.

Xie, Elwi, and MacGregor (1995) investigated the mechanical properties of 60, 90, and 120MPa (8,700, 13,000, and 17,400 psi) concretes. The objective was to determine the compressive cylinder strength, split-cylinder tensile strength, fracture energy using notched beams, and the maximum and residual triaxial strengths. Load deflection curves for fracture energy were analyzed. They show that an increase in compressive strength of concrete increases the peak load of the curve followed by a steeper gradient of the softening branch. They also found that an increase in compressive strength of about 25 percent corresponds with an increase in fracture energy of only 10 percent.

Perdikaris and Romeo (1995) investigated the effect of beam size, aggregate size, and compressive strength on the fracture energy of plain concrete. Concretes with cylinder compressive strengths of 28MPa (4,000 psi) and 55MPa (8,000 psi) and maximum aggregate sizes of 6mrn (Y. in.) and 25mrn (1 in.) were tested. The results indicate that aggregate size has a considerable influence on fracture energy. For both the normal and the high-strength concretes with 25mrn (1 in.) aggregate, fracture energy was about twice the fracture energy of the concretes containing 6mrn (Y. in.) aggregate. They concluded that, for concrete with the larger aggregate, there is a higher degree of matrix-aggregate interlock, resulting in an increase in the energy required for crack propagation.

Maher and Darwin (1976, 1977) observed that the bond strength between the interfacial region and aggregate plays a less dominant role in the compressive strength of concrete than generally believed. Finite element models were used to evaluate th effect of matrix-aggregate bond strength on the strength of concrete. They observe that an increase in bond strength from normal values to perfect bond (no failure at the interface) resulted in only a 4 percent increase in compressive strength of the model. A decrease to zero interfacial strength resulted in a decrease in compressive strength of just 11 percent. The lack of sensitivity in bond strength to changes in water-tocement ratio, demonstrated in earlier tests (Hsu and Slate 1963, Taylor and Broms 1964), provides strong support for the matrix, rather than the interface, as the principal controlling factor in the strength of concrete.

Gettu, Bazan!, and Karr (1990) studied the fracture properties and brittleness of concrete with compressive strengths in excess of 84MPa (12,200 psi) using three point bend specimens. They have observed that cracks in high-strength concrete containing gravel propagated through the coarse aggregate, while cracks in normal strength concrete propagated mainly along the matrix-aggregate interface. The reduced crack area is due to the strong matrix-aggregate bond and the strength of the matrix itself, which approaches the strength of the aggregates, resulting in a more homogeneous behavior. They observed, however, that a 160 percent increase in compressive strength results in an increase in fracture energy of only 12 percent.

III. MATERIALS AND METHODS

3.1. GENERAL

In the present chapter, the physico-chemical properties of cement, aggregate and water used in the investigation were analyzed based on and also the standard experimental procedure laid down in the standard codes, like IS, ASTM and BS codes. These standard experimental procedures were adopted for the determination of normal consistency, initial and final setting times, and soundness of cement and compressive strength of high strength concrete mixes. In establishing these requirements, careful consideration of properties of locally available materials has to be accounted for.

3.2. MATERIALS

The material used in the experimental investigation include

1. 53 grade Bharathi ordinary Portland Cement (opc)
2. Aggregate
    A) Fine aggregate
    B) Coarse aggregate
3. Water
4. Basalt Aggregate

3.2.1 CEMENT

The Locally available cement like Bharathi Ordinary Portland Cement (OPC) of 53 grade of Cement Brand conforming to ISI standards has been procured and various tests have been carried out according IS 8112-1989 from them it is found that,

TABLE .1 THE CHEMICAL COMPOSITION OF CEMENT

Oxide	Cement
SiO2	20.65
Al2O3	5.6
Fe2O3	4.13
CaO	61.87
MgO	2.6
SO3	2.79
K2O	0.83
Na2O	0.14
Loi	1.43

3.2.1.2. TEST RESULTS

a. Specific gravity of for that Cement is 3.15

b. Initial and Final setting times of Cement are 45min and 420min respectively

c. Fineness of that cement is 3%

3.2.1 FINE AGGREGATE-

The locally available natural river sand is procured and is found to be conformed to grading zone-II of Table *** of IS 383-1970. Various tests have been carried out as per the procedure given in IS 383(1970) from them it is found that,

Figure .1. Set of Sieves for Fine Aggregate

3.2.1.1 Test results

a) Specific Gravity of that fine aggregate is 2.66

b) Fully compacted density of that fine aggregate is 1670 kg/m3

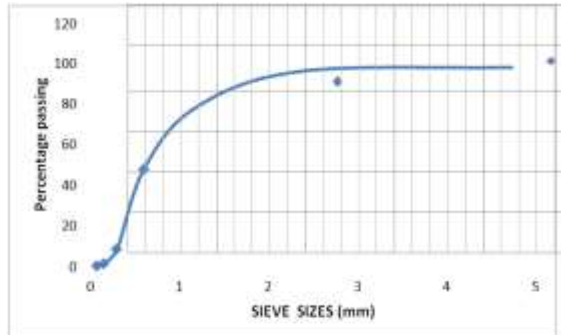
c) Partially compacted density of fine aggregate is 1500 kg/m3

d) Fineness Modulus of Fine Aggregate is 3.20

The sieve analysis results are presented in Table 3.2 and curve for this ispresented in graph 1 .The set of sieves is shown in

TABLE .2 SIEVE ANALYSIS OF FINE AGGREGATE

S No	IS Sieve No	Weight Retained (in grams)	Cumulative weight Retained (in grams)	Cumulative Percentage Weight Retained	Cumulative Percentage Weight Passing
1	4.75	20	20	2	98
2	2.36	20	40	4	96
3	1.18	180	220	22	78
4	0.6	305	525	52.5	47.5
5	0.3	395	920	92	8
6	0.15	70	990	99	1
7	0.075	10	1000	100	0
8	Pan	0	1000	100	0



Graph .1SIEVE ANALYSIS OF FINE AGGREGATE

3.1. BASALT AGGREGATE

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 "trap rock.

Table 3. Chemical Composition of Basaltic aggregate

Compound	Percentage
Silicon dioxide	48.0
Aluminum oxide	14.4
Iron oxide	15.1
Calcium oxide	6.18
Magnesium oxide	5.95
Sodium oxide	4.05
Potassium oxide	2.29
Titanium oxide	2.29
Other oxides	1.74

IV. RESULTS AND DISCUSSIONS

4.1 GENERAL

The purpose of this research is to investigate the feasibility of using basalt aggregates in concrete mixes. Theresearcher has designed an elaborate experimental program that included a variation of basalt percentages inconcrete mixes. The laboratory investigation included measurements of compressive strength, indirect tensilestrength, flexural strength,. Two different sets of specimens are prepared usingdesign mixes M50 and M60 for each set respectively.In each set, the specimens are casted by varying thepercentage of replacement of coarse aggregate (limestone) with basalt aggregate starting from 0 to 100%with an increment of 25% by weight of coarseaggregate and they are represented as0%,25%,50%,75%,100% respectively. In the secondset, the former procedure is followed; in addition tothat mineral admixture of 7.7% by weight of cementis replaced. Cubes with size 150mm X150mm X150 mm, areprepared.

4.2. DISCUSSION OF THE RESULTS

The results of the experimental investigations are presented and discussed herein. The experimental program was designed to compare the mechanical properties i.e., Compressive Strength of Cubes & Cylinders, Flexural Strength, Splitting Tensile Strength and Modulus of Elasticity of high strength concrete with M50 and M60 grade of concrete and with different replacement levels of Ordinary Portland cement (Ultra Tech cement 53 grade) with basalt.

The program consists of casting and testing a total of 240 specimens. The specimens of standard cubes (150mm x 150mm x 150mm), Standard Cylinders of (150mm Dia x 300mm height) and standard prisms of (100mm x 100mm x 500mm) were cast with basalt. Compression testing machine was used to test all the specimens. In first series the specimens were cast with M50 grade concrete with different replacement levels of coarse aggregate as 0%, 25%,50% and 75%,100% with basalt aggregate. And in the second series the same levels of replacement with M60 grade of concrete were cast.

4.3 COMPRESSIVE STRENGTH TEST RESULTS (M 50)

This test was performed according to theBritish Standard (B.S. 1881, part 3).Table5 to table 8 and Figure 2 show the results of thecompressive strength tests that were conducted on thetrial mixes containing 0%,25%, 50%,75% and 100%basalt, respectively. In general, the compressive Strength increased as the percentage of basalt contentin the mix is increased.

Table 5. 3 days compressive strength test results for M 50 grade concrete mix in N/mm^2

Specimen	0% basalt		25% basalt		50% basalt		75% basalt		100% basalt	
	Load	Avg Load	Load	Avg Load	Load	Avg Load	Load	Avg Load	Load	Avg Load
1	28		32.56		34.66		38.33		40.60	
2	30.45	29.81	33.25	33.39	36.55	36.10	40.88	39.88	42.11	42.18
3	31.00		34.36		37.11		40.44		43.77	

Table: 6. 7 days compressive strength test results for M 50 grade concrete mix in N/mm2

Specimen	0% basalt		25% basalt		50% basalt		75% basalt		100% basalt	
	Load	Avg Load	Load	Avg Load	Load	Avg Load	Load	Avg Load	Load	Avg Load
1	39.83		40.26		41.25		42.15		42.98	
2	40.56	40.86	41.25	41.58	43.56	42.35	42.28	43.09	45.36	45.3
3	42.15		43.25		42.25		44.86		47.56	

Table: 7. 28 days compressive strength test results for M 50 grade concrete mix in N/mm2

Specimen	0% basalt		25% basalt		50% basalt		75% basalt		100% basalt	
	Load	Avg Load	Load	Avg Load	Load	Avg Load	Load	Avg Load	Load	Avg Load
1	60.25		62.33		66.78		66.45		68.56	
2	59	60.75	63.86	63.46	64.18	64.94	69.45	65.56	69.45	66.33
3	63		64.21		63.86		67.6		67.6	

Table 8 :56 days compressive strength test results for M 50 grade concrete mix in N/mm2

Specimen	0% basalt		25% basalt		50% basalt		75% basalt		100% basalt	
	Load	Avg Load	Load	Avg Load	Load	Avg Load	Load	Avg Load	Load	Avg Load
1	61.51		63.59		68.04		67.71		69.82	
2	60.26	62.01	65.12	64.72	65.44	66.2	66.61	66.82	70.71	69.79
3	64.26		65.47		65.12		66.15		68.86	

V. CONCLUSIONS

Based on the present experimental investigation, the following conclusions are drawn

1. While using the basalt in concrete the original water cement ratio of concrete mix is to be corrected by the amount of water available in basalt aggregate.
2. The laboratory test results in compressive strength, seems to indicate that the increase in basaltpercentage enhances the mix strength. This is due to the factthat basalt is denser and more durable and less water absorbing than limestone. Also higher workability is obtained for more basalt aggregate content mix which reduces the cost of labor.
3. As basalt aggregate is a natural aggregate also available in plenty at low cost, an economical and relatively high strength concrete is obtained by using basalt aggregate as coarse aggregate in concrete mixes.
4. Coarse aggregate replacement with 25% basalt to increase in Compressive Strength, Split Tensile Strength.
5. For M50 Grade with basalt 25%, 50% 75%, 100% the percentage increase in Compressive Strength, Split Tensile Strength are 25.21%,10.5%.
6. For M60 Grade with basalt aggregate25%, 50% 75%, 100% the percentage increase in Compressive Strength, Split Tensile Strength are 6.46%, 4.62 % respectively.
7. There is an increase in Compressive Strength of Cylinders for M50 & M60 with basalt100% is 27.12 % and 24.91 % respectively higher than Conventional Concrete

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