Utilization of Steel Slag and Fly Ash in Rigid Pavement and Its Economic Evaluation

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Abstract— In India, the present rate of utilization of waste material is only about 10 percent, which is below the world average of about 16 percent. Hence in these Studies, it is aimed to describe the use of fly ash and steel slag in rigid pavement road works and its improvement of strength with compare to the conventional concrete its economic evaluation for the suitability of using of it. The global demand of concrete in the future is more challenging task to find the suitable alternatives of natural aggregates, sand and cement for preparing concrete. Rigid pavement is the one type of pavements which resists more against the external loads and long life period if it is well designed. Rigid pavement structure is composed of a hydraulic cement concrete surface course and underlying base and sub base courses. Concrete is prepared by mixing various constituents like cement, aggregates, water, etc. which are economically available. Concrete plays a critical role in the design and construction of the nation's infrastructure. Almost three quarters volume of concrete is aggregates and the important content of concrete is cement. We have to find the suitable and economical alternatives for both of these materials.

Key words: Steel slag, Fly ash, Aggregates, Rigid Pavement, Concrete mix, Strength, Economic Evaluation

I. INTRODUCTION

The utilization of waste material is the important and more challenging task in construction works. The work ability, mechanical properties, availability of waste materials, quantity of production of it and its economically cost are the very important properties, which should take in account for utilization of those waste materials.

A highway pavement is designed to support the wheel loads imposed on it from traffic moving over it. Additional stresses are also imposed by change in the environment.

Concrete pavement as pavement in which derives its capacity to withstand loads from the flexural strength or beam strength (modulus of elasticity), permitting the slab to bridge over minor irregularities in the sub grade, sub base or base upon which it rests.

This implies that the inherent strength of the slab its self is called upon to play a major role to resist the wheel loads.

A rigid pavement structure is typically composed of PPC (mostly) surface course built on top of either, the sub grade and underplaying base. It is consisted the following parts:

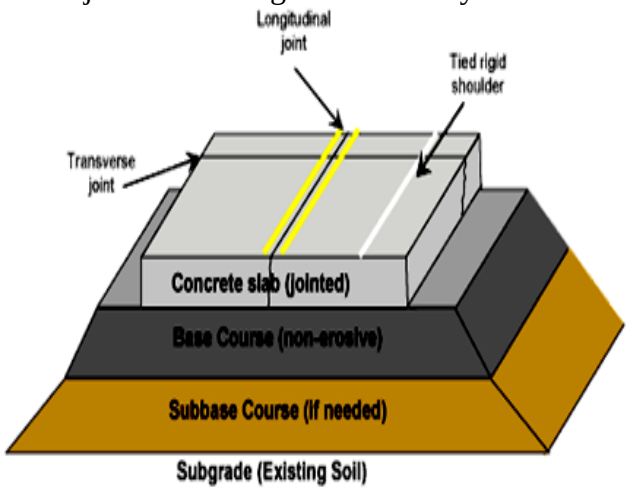

Fig. 1: shows the different layers of rigid

Cement is the most important component of concrete, which is working in combination of the mix materials and increases the strength of concrete. The 75 % of concrete mix material is Aggregate. It is also playing important role in construction works, especially in concrete.

To find out the suitable and economical alternatives for both of these materials, we have to conduct laboratory tests of fly ash and steel slag, which have the smeller mechanical and chemical properties with cement and aggregates, because both of these materials are waste and by-product materials.

Steel slag is a co-product of the steel making process in which Steel cannot be prepared in the Basic Oxygen Furnace (BOF) or in an Electric Arc furnace (EAF) without making its co-product; steel slag. The use of steel slag aggregates in concrete by replacing natural aggregates is a most promising concept. Steel slag aggregates are already being used as aggregates in concrete paving road mixes due to their mechanical strength, stiffness, porosity, wear resistance and water absorption capacity.

The Fly ash is also by-product material of coal, which uses in furnaces for producing of heat and high temperature. Fly ash is the west material of coal combustion in furnaces.

Fly ash is already being used in 15-30 % ratios of cement in concrete as a replacement of Portland cement duo to their physical and mechanical properties and similarity with cement.

There are we conducted experimental tests on conventional and modified concretes.

In these studies, several experiments have been conduct to study the effect of adding steel slag aggregates and fly ash in concrete composite and to find out the optimum ratio of waste materials in concrete mix which given us the maximum strength and its economic evaluation.

Following are objectives of the studies:

- To compare various results with conventional concrete and modified concrete.
- To compare the cost of conventional and modified concrete.

The Basic scope of this research is to investigate the properties of concrete with steel slag aggregates and fly ash cement, and economical evaluation of suitable sample.

- To carry out physical tests on the aggregates, steel slag as per IS: 383 and fly ash as per IS: 3812 Guidelines.
- To design a concrete mix for M30 as per IS: 10262 Guidelines.
- To conducted required tests such as compressive strength, flexural strength as per IS: 516, and split tensile strength as per IS: 5816, of conventional and modified concrete.
- Replacing the conventional mix materials in concrete by steel slag and fly ash would be in percentage of 0, 10, 20, 30, 40 & 50% and 0, 05, 10, 15, 20, 25 of each natural aggregate and cement respectively.

II. MATERIALS

Concrete is composed by different materials such as aggregates, water, cement as termed as binder because it brings the cohesiveness between the all ingredients combined together for producing one material called concrete. We have used in these studies fly ash and steel slag also among the other components of concrete:

A. Cement:

In these studies, ordinary Portland cement of 53 grades has been selected to be used in concrete mix, and its physical requirements are established according to India specification (IS-12269).

Fig. 2: shows the sample of OPC in bag and lose

B. Aggregates:

Aggregate is an inert, inexpensive material dispersed throughout the cement paste so as to produce a large volume of concrete.

Fig. 3: shows the sample 20 mm Aggregates

C. Fine Aggregates:

Fine aggregates are the aggregates' passing through 4.75 mm IS sieve.

Fig. 4: shows fine Aggregates passing of 4.75 mm sieve

D. Flay Ash:

Fly ash is the west material of coal combustion in furnaces.

Fly ash is already being used in 15-30 % ratios of cement in concrete as a replacement of Portland cement

Fig. 5: shows the sample of Fly ash C

E. Steel Slag:

Based on the definition of steel slag as by-product of industry steel making which can be produce by oxygen furnace or electric arc furnace. It is produced in the form of rocks which is ground into small particle size as fine or coarse steel slag for construction purpose.

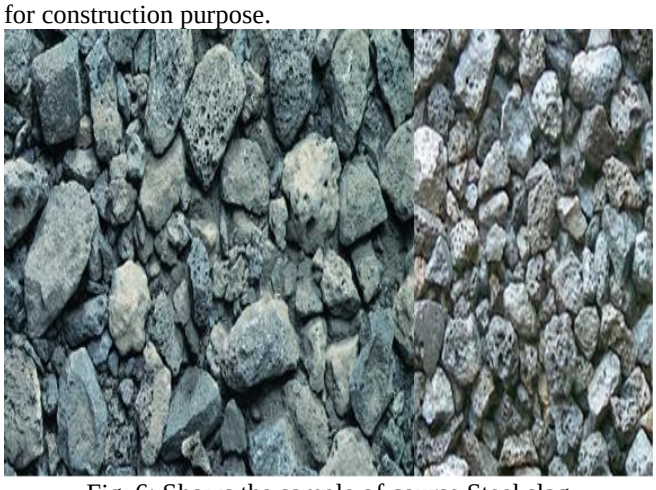

Fig. 6: Shows the sample of course Steel slag

F. Water:

Water is important ingredient of concrete as it actively participates in chemical reaction with cement. The specific gravity of water as specified by Indian standard code is 1.0. The quality of water is important because impurities in it may

interfere with the setting of cement may adversely affect the strength of the concrete.

III. EXPERIMENTAL RESULTS

This chapter has been focused on the determination of the quantity of concrete ingredients required to produce the good concrete mixes as well as the required strength. The materials used in these studies are available locally and research materials as fly ash and steel slag has been found in Ahmedabad. It is discussed also the results obtained from different experiments for grading of aggregates, fresh and hardened concrete.

In order to evaluate the strength of concrete, the three specimens are casted and tested for each age according to Indian standards.

The data collected from laboratory are summarized in the form of tables and charts in order to simplify the understanding of results obtained.

A. Grading Of Aggregates:

The materials used in these studies are found locally, the coarse aggregates of 10 and 20 mm are used and replaced by the steel slag of 10 and 20 mm size and Portland cement replaced by fly ash C respectively.

The fine aggregates used in these studies are also found locally as river sand.

The specific gravity water absorption Bulk density aberration value of aggregates and steel slag are shown chart:

S/N	Type of properties	Aggregate	Steel slag
1	Specific gravity	2.54	3.29
2	Water absorption %	0.69	0.37
3	Bulk density kg/ m^3	1685	1770
4	Abrasion Value	12.63	10.65

Table 1: mechanical properties of steel slag & aggregates

Fineness modulus of sand, coarse aggregates and coarse steel slag as per IS: 2386 are 2.58, 8.10, and 8.41 respectively.

B. Mix Proportion Of Concrete:

According to bureau of Indian standard guideline described in literature review, the mix design is required to select the suitability of materials as well as determination of quantity required in mix for producing the good concrete.

The materials used in these studies are aggregate, sand, cement and water.

The following information is considered in determination of mix proportion:

- Grade of concrete: M30 and Grade of cement: 53 OPC
- Maximum nominal size of aggregates: 20 mm
- Workability of required: 50 to 70 mm and Maximum water cement ratio: 0.45
- Type of aggregate: crushed angular aggregate and sand
- Minimum and maximum cement content: 360 to 540 kg/m3 thereafter the all required quantities were determined according to IS: 10262-2009.

Summary of all data calculated in the form of tables as shown below:

Description	Mix proportion in kg/ m^3				
Ingredients	Water	Cement	Sand	Course Agg.	U. weight kg /m^3
Weight (kg)	186	443	664.5	1143	2436
Per bag of cement	20.09	1 (50 kg)	75	129	
Per W/C ratio	0.42	1	1.5	2.58	

Table 2: mix design and proportion of materials

Numbers of specimens and quantity of mix materials for each trail of mix proportion in these studies are:
6 Cubes (15x15x15) cm for 7 and 28 days curing
6 Cylinders (15ØX30) cm for 7 and 28 days curing
3 Beams (15X75) cm for 28 days curing

Quantity of Mix materials for each proportion of these studies are in kg/cc.

S/N	% of Fly ash	% of slag	water	cement	Fly ash	sand	C. Agg 20 mm	S. slag 20 mm	No of specimens
1	0	0	20.09	50	-	75	129	-	15
2	05	10	20.09	47.5	2.5	75	116.1	12.9	15
3	10	20	20.09	45	05	75	103.2	25.8	15
4	15	30	20.09	42.5	7.5	75	90.3	38.7	15
5	20	40	20.09	40	10	75	77.4	51.6	15
6	25	50	20.09	37.5	12.5	75	64.5	64.5	15

Table 3: proportion of mix materials for 6 trails of concrete

C. Experimental Results:

The concrete mix proportion used in these studies is 1:1.5:2.58 with the water cement ratio of 0.42.

The concrete mix of M30 is selected in these studies as per rigid pavement requirement. According to Indian standard referred for performing different laboratory experiments, the two types of concrete properties are evaluated.

1) Fresh Concrete:

Fresh concrete is the property of concrete which is evaluated in term of workability by slump and compaction factor test. The bulk density (unit weight) is also tested; the following table and pictures show the results and work of fresh concrete's tests of four trails of conventional and modified concrete:

Test results of fresh concrete for all trails of concrete					
Trail Mix	Fly ash %	Steel slag %	slump (mm)	Compaction factor (ratio)	U. weight kg/m^3
M1	0	0	55	0.8	2436.5
M2	5	10	60	0.82	2439.4
M3	10	20	60	0.85	2443
M4	15	30	65	0.87	2447.5
M5	20	40	70	0.89	2457
M6	25	50	70	0.9	2463

Table 4: result of fresh concrete's tests for all trails

2) Hardened Concrete:

The important property of hardened concrete is the strength which is evaluated in term of compressive, flexural, split tensile strength in these studies. The different specimens are casted for each trial of mix.

According to Indian standard, the minimum 3 specimens are casted for each age of curing (7&28 days) and tested.

a) Compressive Strength:

The compressive strength of hardened concrete is tested according to Indian standard (IS-14858:2000). The 3 specimens of cubes (15*15*15 cm) were casted and tested for age of 7 and 28 days. The plane area of specimen (cubes) is calculated (150*150) mm and obtained 22500 mm2. The following pictures and figures show the research work in the laboratory for different experiments:

Compressive strength in Mpa					
Trail mix	% of Replaced materials		Results		Target strength
	Fly ash	Steel slag	7 days	28 days	
M1	0	0	25	38.7	38.25
M2	5	10	25.3	38.9	38.25
M3	10	20	25.5	39.1	38.25
M4	15	30	25.6	39.1	38.25
M5	20	40	23.3	35.9	38.25

Table 5: results and limitation of Compressive strength

b) Split Tensile Strength:

The tensile strength of hardened concrete is tested according to Indian standard (IS: 5816-1970). The 3 specimens of cylinder are casted and tested for each 7 and 28 days of curing. In these studies, the 7 and 28 days of curing are presented for conventional and modified concrete.

The specimens are tested horizontal with the area equal 141372 mm2.

The split tensile strength of concrete should be between 8 to 12% of compressive strength results.

The split tensile strength is found between 9 and 12% of compressive strength results as shown in the figure and table below:

Split tensile strength in Mpa					
Trail mix	% of Replaced materials		Results		Target strength
	Fly ash	Steel slag	7 days	28 days	
M1	0	0	2.45	3.70	3.06 – 4.59
M2	5	10	2.60	3.83	3.06 – 4.59
M3	10	20	2.71	3.90	3.06 – 4.59
M4	15	30	2.90	4.15	3.06 – 4.59
M5	20	40	2.85	4.05	3.06 – 4.59

Table 6: results and limitation of split tensile strength

c) Flexural strength

Flexural strength of hardened concrete is evaluated according to Indian standard (IS: 516 - 1959).

The 3 specimens of beams (15*15*75 cm) are casted and tested for 28 days of curing.

The flexural strength test of both conventional and modified concrete is also carried out for checking the modulus of rupture. In the below table shows the average results in which modified concrete performed better with compare to conventional concrete.

Flexural strength in Mpa				
Trail mix	% of Replaced materials		Results	Target strength
	Fly ash	Steel slag	28 days	
M1	0	0	3.85	3.6 – 7.6
M2	5	10	3.98	3.6 – 7.6
M3	10	20	4.12	3.6 – 7.6
M4	15	30	4.20	3.6 – 7.6
M5	20	40	3.9	3.6 – 7.6

Table 7: results and limitation of Flexural strength

D. Summary of Tests Results:

The experimental results described in this chapter have presented for both conventional and modified concrete. The different tests performed for fresh concrete proved that fly ash and steel slag are the best waste materials to be used in road construction.

The results obtained from 7& 28 days of compressive strength test have demonstrated the required targeted strength (38.25 Mpa) is achieved.

Split tensile strength result is found as 10% of compressive strength as specified by bureau of Indian standard code.

Flexural strength results also show that the increasing the waste materials %, the strength increased considerably.

The both fly ash and steel slag could be used as the mix materials in place of natural aggregates and cement if locally and economically available.

There is we conducted excremental tests on five trails of modified concrete, in which the last trail failed and trail no. 4 gave us the optimum strength (39.1 Mpa).

Finally the result carried out that the proportion number 4 is the suitable replacement proportion in which we replaced the 15 % of cement by fly ash and 30 % of aggregates by steel slag.

IV. COST COMPARISON

The one of important aims of this research is economical evaluation of the conventional and modified concrete, which is dependent to the economical evaluation of concrete's contents (Aggregates, sand, cement, fly ash, steel slag, water etc.)

Cost of materials is related to the quantity of production, locality available, transportation expenses and demand of the market. In these studies we used the crushed aggregates of 20 mm and river sand which are available generally in Ahmedabad city if Gujarat-India. We have used the Portland cement of UltraTech Company which is uses in construction works in Gujarat in generally. We have collected Fly ash C material from Ahmedabad torrent power thermal station and steel slag collected from Nendeshwari Steel Industry Ltd in Zaak GIDC Dehgam Road Ahmedabad.

First of all we have to summarize the mix proportion of conventional and modified concert:

MIX	% of Fly ash	% of slag	water	cement	Fly ash	sand	C. Agg 20 mm	S. slag 20 mm	Total weight (kg)
M1	0	0	20.09	50	-	75	129	-	274.09
M2	05	10	20.09	47.5	2.5	75	116.1	12.9	274.09
M3	10	20	20.09	45	05	75	103.2	25.8	274.09
M4	15	30	20.09	42.5	7.5	75	90.3	38.7	274.09
M5	20	40	20.09	40	10	75	77.4	51.6	274.09

Table 8: summary of proportion of all trails of concrete

As per local market prices the summary of concrete materials costs are:

Cement: 5800 INR/ Tone = 5.8 INR/kg
Sand: 1250 INR/ Tone = 12.5 INR/kg
Aggregates: 1330 INR/ Tone = 1.33 INR/kg
Fly ash: 500 INR/ Tone = 0.5 INR/kg
Steel slag: 2500 INR/ Tone = 2.5 INR/kg

Thus, the costs for all proportion of modified and conventional concrete per one cubic meter concrete are:

Cost of All mix proportions and comparison for 1 Cubic M							
Trail	Description	Cement	Sand	Course Agg.	Fly ash	Steel slag	Water
M1	Proportions per 1 M^3 concrete	443	664.5	1143	0	0	186
	Price of material /1 kg	5.8	1.25	1.33	0.5	2.5	Free of Charge
	Total price of each	2569.40	830.63	1520.19	0.00	0.00	
	Grand Total for Cubic M concrete (INR)	4920.22					
M2	Proportions per 1 M^3 concrete	420.85	664.5	1028.7	22.15	114.3	186
	Price of material /1 kg	5.8	1.25	1.33	0.5	2.5	Free of Charge
	Total price of each	2440.93	830.63	1368.17	11.08	285.75	
	Grand Total for Cubic M concrete (INR)	4936.55					
M3	Proportions per 1 M^3 concrete	398.7	664.5	914.4	44.3	228.6	186
	Price of material /1 kg	5.8	1.25	1.33	0.5	2.5	Free of Charge
	Total price of each	2312.46	830.63	1216.15	22.15	571.50	
	Grand Total for Cubic M concrete (INR)	4952.89					
M4	Proportions per 1 M^3 concrete	376.55	664.5	800.1	66.45	342.9	186
	Price of material /1 kg	5.8	1.25	1.33	0.5	2.5	Free of Charge
	Total price of each	2183.99	830.63	1064.13	33.23	857.25	
	Grand Total for Cubic M concrete (INR)	4969.22					
M5	Proportions per 1 M^3 concrete	354.4	664.5	685.8	88.6	457.2	186
	Price of material /1 kg	5.8	1.25	1.33	0.5	2.5	Free of Charge
	Total price of each	2055.52	830.63	912.11	44.30	1143	
	Grand Total for Cubic M concrete (INR)	4985.56					

Table 9: summary of costs of all trails of Mix in details

As per overall results the trail number 4 is the optimum trail, which is given the highest strength of concrete. In trail number 4 the replaced materials are used 15 % of fly ash and 30 % of steel slag as a suitable replacement of cement and aggregates.

In table 9 shows the cost per one cubic meter concrete of trail number 4 greater than conventional concrete's cost (4920.22 > 4969.22), but it is not the widely difference between those kinds of concrete, because there is modified concrete is just 1% costly compare to the conventional concrete. Here is the highest performance of modified concrete is taking into account.

The cost comparison of all types of concrete has done by the local prices of Ahmedabad city in Gujarat of India. There is the cost of water and labor is not counted in this evaluation.

Finally we can select the trail number 4 for it is best performance and economical cost of it is mix materials as suitable replacement proportion of conventional concrete in Ahmedabad.

V. Conclusion

The effect of steel slag and fly ash on the properties of concrete mix for rigid pavement in the main research work have carried out in these studies, thereafter the comparison between the both conventional and modified concrete have considered in order to cheek the suitability of optimum quantity of waste materials and concrete mix and their effects on it.

The Physical and mechanical properties of steel slag as well as other concrete materials have been evaluated according to Indian specification requirements. The all basic properties of fresh and hardened conventional and modified concrete have also evaluated. The concrete mixes of M30 grades and ordinary Portland cement of 53 grades have been selected in this research. The water cement ratio calculated from mix design was 0.42.

The experimental results of both (conventional and modified) concrete in included in this report. The following conclusions are written based on the context of this report:

- Steel slag is a by-product of the steel making process, which is already being used as aggregates in concrete paving road mixes due to their mechanical strength, stiffness, wear resistance and water absorption capacity.
- The Fly ash is also by-product and waste material of coal combustion in thermal power houses. Fly ash is already being used in 15-30 % ratios of cement in concrete as a replacement of Portland cement duo to their similar physical and mechanical properties.
- In these studies, the replacement on aggregates and cement by steel slag and fly ash percentage such as 0, 10, 20, 30, 40, 50% and 0, 5, 10, 15, 20, 25% respectively.
- Fly Ash & Steel slag could be used in concrete mix because of its suitable Physical and Mechanical properties.
- The fresh modified concrete results show that fly ash & steel slag could be used as alternative concrete materials.
- The compressive, Split tensile and flexural strength of conventional concrete is less than modified concrete up to Trail Mix No 4, but in Trail no 5, it is not achieved the required strength.
- As per experimental results we can select trail no 4 (replacing of 15 % of flay ash and 30 % of steel slag) as optimum replacement of aggregates and cement for 30 Mpa concrete.
- As per cost comparison of conventional and modified concrete, if the fly ash and steel slag as co-product materials could be locally available, are cheaper than cement and aggregates.
- The use of these waste materials would also lead to save the natural resources from reducing more consumption in construction of structures.

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