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Experimental Study of Strength & Rutting Characteristics of WBM with Partial Replacement of Aggregates by Steel

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Abstract:

Utilizing industrial by-products is a major task in the current scenario of rapid industrial growth all around the globe. Many industrial wastes/by-products are suitable for use in various constructions. In highway constructions the most generally used by-product is fly ash from thermal power stations. Rice husk ash is also used along with lime, lime-flyash lime-rice husk ash are different combinations usually adopted. Recycled concrete aggregates, municipal wastes processed with proper techniques, quarry wastes and slurry dust from marble polishing plants are other wastes used in highway construction. Steel production is marked as the backbone of developmental economies in the history of modern nations. It is one of the very few materials which are multi-functional and most-adaptive in its usage. Steel production is also seen as strategic part any country's economy, currently China is the highest producer of steel with803.8 million metric tons and India occupies 3rd position with 89.4 million tons as per the data released by World Steel Association based in Brussels for the year 2015. Blast furnace slag, Granulated Blast Furnace Slag (GBFS) and Steel slag are three different by-products from iron and steel industries located in various parts of our country. Feasibility study to utilize them instead of conventional road aggregates was done by CRRI. Air cooled blast furnace slag and weathered steel slag can be used instead of conventional stone aggregates in construction of WBM layers and for mechanical stabilization as per IRC: SP: 20-2002. In the present study coarser fraction of steel slag is being used as coarse aggregate and fines of steel are used as screenings.

Keywords **— GGBS, Roller Compactor cum Rut Analyzer, compaction and rutting**

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I. INTRODUCTION

Water Bound Macadam (WBM) is a layer which can be used as a sub-base or base or surface course, it consists of mechanically interlocked aggregates with its voids filled by screenings and binder with aid of water. It was originally introduced by a Scottish engineer John.L.Macadam in 1820 as comprising of only aggregates meeting a specific gradation to form a mechanically interlocked mix compacted with light application of water. It had various defects like frequent loss of aggregates and poor engineer by name Richard Edgeworth modified it by adding fine screenings of the same material as that of aggregates to fill voids in aggregates and a binder with aid of water for proper binding of the mix. This modified WBM had comparatively more durability and good ride quality.In our country WBM is mainly used as a base course for important roads like NH because of its good drainage characteristics, however for low volume roads it is used as a surface course also. IRC:19-2005 deals exclusively with specifications for materials and construction of water bound macadam layer. Similar details about WBM are noticed in IRC:37-2012 for roads with volume more than 1msa and in IRC:SP:20-2002 & IRC:SP:72-2015 for low volume rural roads i.e. less than 1msa.Water Bound Macadam (WBM) consists of coarse aggregates, screenings and binder. Coarse aggregates used should be clean free from dirt and any deleterious matter. Crushed stones, crushed slag, kankar, laterite or over burnt bricks can be used as aggregates. Aggregates should be chemically stable and water absorption should not exceed 10 percent. There are 3 sets of grading requirements for coarse aggregates of different sizes, namely Grade-1, Grade-2 and Grade-3. However only Grade-3 is used for surface course and remaining two namely Grade-1 and Grade-2 are used for sub- base and base course only. The compacted thickness of Grade-1 is 100mm where as that of Grade-2 and Grade-3 is 75mm each. Also the aggregates should have permissible Los Angeles abrasion and aggregate impact value. Screenings which fill the voids should be as far as possible of the same material as that of coarse aggregates. There are two sets of gradations available for screenings viz. Type A and Type B. Type A screenings can be used with Grade-1 and Grade-2 coarse aggregates. Type B screenings can be used with Grade-2 and Grade-3 coarse aggregates. Binding material is used in WBM in order to hold the mix together with aid of water. Binding material is fine grained material having permissible values of plasticity index depending upon the climatic conditions of road. Dust (soil or lime stone dust), kankar nodules or any other locally available fine grained material may.

II. Litreture Review

A. **G.MadhaviLatha,etal.,(2010)[1]**carriedoutrutt ingstudiesonunpavedroads.They constructed a 2m long and 1m wide unpaved road over a subgrade prepared by in situ natural soil in the IIScampus. Grid points were placed across the road with equal spacing of 10cm, 11 such grid points were in place at each section and a total of 3 such sections were made along the road to monitor the rut depth when a scooter weighing 106kg moved on it at an average speed of 20kmph. Unreinforced and reinforced roads rut depths and traffic benefit ratios were compared to evaluate reinforcing materials. Unreinforced road was simply prepared by laying a 100mm thick properly blended aggregate layer over well compacted subgrade. Over this in- situ drysoilwasplacedand compacted with appropriate quantity of water to provide a good riding surface which was 50mm thick. Different reinforcements used in the study were geotextiles, biaxial geogrid, uniaxial geogrid, geocell layer and tyre shreds. Reinforced sections were prepared by placing the respective reinforcements at the interface of aggregate layer and subgrade. Unreinforced section performed very poorly in rutting test whereas all reinforced sections performance was considerably good. Among reinforced sections, geocell layer outperformed tyre shreds, which performed better than geotextiles. The ratio of number of passes required to cause a certain permanent deformation i.e. rutdepthina reinforced layer thickness is Traffic Benefit Ratio (TRB). Even in terms of TRB geocell layer performed better than other reinforcements, followed by tyre shreds and geotextiles

B. **B.V. Kiran Kumar, et al., (2012)[2]** indigenously built an equipment called Roller Compactor cum Rut Analyzer (RCRA) which is capable of performing both compaction and rutting on a layer. Its outstanding feature is that, it simulates field conditions of compaction and rutting in laboratory. Unlike other equipments in laboratory which compact by use of rammers which is not a practice in field, RCRA compacts a layer by kneading effect thus simulating field method of compaction. It has two dispatch able rollers, one a smooth wheeled uniform diameter roller for compaction and another rutting roller with two discs mounted on steel bar representing axle of vehicle. These rollers can be used as per the requirement, can apply a constant pressure varying from 0.6N/mm2 up to 3 N/mm2. It has a set of vertical and horizontal transducers which are capable of measuring movements and Theresa Programm able Logical Circuit with control screen for monitoring, recording and operating. They prepared Bituminous Concrete (BC) grade-2 specimens using Marshall Hammer, Super pave Gyratory compactor (SGC) and Roller Compactor cum Rut Analyser (RCRA). Optimum binder content (OBC) of specimens by these three different methods of compaction were compared, SGC specimens resulted in lowest OBC followed by RCRA for the same binder and air voids. SGC specimens had the highest stability, and those by RCRA were close to SGC followed by Marshall Hammer which were too low, the same trend was observed in density too

C. **ErolTutumluer, et al., (2016)**[(3)]conducted cyclic loading test on non-bituminous layerto evaluate effectiveness of geo-synthetic fibre reinforcement in case of unpaved roads. Steel mould measuring 2x2x2m was fabricated to house pavement material to be tested. A cyclic loading arrangement consisting of jack and a steel plate of 300 diameter capable of applying upto 40kN load at a particular load pulse frequency was mounted over the steel box. A set of transducers and load cells measured vertical movement of plate and number of cycles. Weak subgrade soil was placed in layers and each was compacted with appropriate quantity of water, final thickness of this subgrade soil layer was 140cm. Tests were conducted in two sets, in the first they varied thickness of granular sub-base layer placed over subgrade and in the later triaxial geogrid of 40mm triangular aperture made from polypropylene was placed at varying depths of 1/3, 2/3 and one times diameter of steel plate from surface, cyclic load tests was performed for each case to measure permanent deformation. Authors concluded that as the thickness of granular layer increases permanent deformation decreases, whereas with increase in number of cycles they noticed severe deformation. In case of geogrid rein forced layer, it was observed that nearer the geogrid from surface lesser was the permanent deformation. In both cases it was clearly evident that for initial loading cycles rate deformation is high and which decreases at later stages of loading.

D. **Faisal I. Shalabi, et al., (2016)**[(4)]evaluated the efficiency of steel slag in improving performance of local clayey soil of Saudi Arabia. Steel slag aggregates from various steel industries were collected and basic tests were performed. Clayey soil was mixed with varying percentages of steel slag, Atterberg limits, free swell index, shear parameters, compaction characteristics and CBR were obtained by experimental study. It was observed that with increase in steel slag content the treated clayed soil was observed to have a lower plasticity index and free swell index, whereas Maximum Dry Density (MDD) and California Bearing Ratio (CBR) values increased. Unconfined Compressive Strength (UCS) initially decreased with increase in steel slag content, reached a minimum value and then slightly increased. Cohesion value decreased with rise in steel slag content, while increase in friction angle was noticed.

E. **G.Ramulu, et al., (2012)**[(5)]studied influence of gradation of mix, moisture content of subgrade, field density, California Bearing Ratio (CBR) and traffic volume on rutting behaviour of Water Bound Macadam (WBM). The authors selected a total of fifteen 500m stretches spread across three districts of Andra Pradesh having different geological and climatic conditions for field studies using various destructive an dnon destructive methods and post data analysis using appropriate software tools they developed response models. Road inventory, structural and functional evaluation of pavement and volume count was carried on these stretches. Functional parameter roughness was expressed in terms of International Roughness Index (IRI) and some data was collected from secondary sources too. It was notice that closer the gradation curve to upper limit lower was the rut depth. Moisture content of subgrade was observed to have a direct relationship with rut depth whereas field density had an in verse relationship. Based on the literature study it is clearly evident that more investigations on rutting characteristics of non-bituminous courses are required as unsealed surfaces are more susceptible to deformation than sealed roads. An attempt is made to carry out rutting studies on non-bituminous course i.e. WBM while making use.

III. METHDOLOGY

WBM consists of Coarse aggregates, Screenings and Binder, in the present study soil is used as binder and fines of steel slag as screenings. Two combinations of WBM are prepared one with conventional aggregates as coarse aggregates here after this WBM combination is referred as WBM-A and another with partial replacement of conventional aggregates by steel slag here after referred as WBM-B. Steel slag used in WBM-B is coarser fraction.

F. Properties of Aggregate

Various tests on conventional mineral aggregates were carried out as per 'Specifications for Rural Roads' by Ministry of Rural Development (MoRD) (2014) and IRC: 19-2005. The values are tabulated below along with their corresponding limits.

Table 1 Properties of Conventional Aggregates

G. Properties of Steel Slag

Sl. No	Parameter	IS code	Obtained Value	Prescribed limits asper MoRD&IRC: 19-2005
1	Impact value of aggregate	IS:2386 Part4	21%	< 30%
2	Los Angeles abrasion value	IS: 2386Part 4	22%	< 40 %
3	Flakiness index	IS:2386 Part1	2%	< 15%
4	Water absorption	IS:2386 Part3	2%	<10%
5	Crushing value ofaggregates	IS:2386 Part4	24%	<30%
6	Specific Gravity	IS:2386 Part3	2.9	
7	Angularity number	IS: 2386Part 1	9	
8	Bulk Density	IS: 2386Part 1	15.21 kN/m^3	>11.2 kN/m^3

Steel slag obtained from Kalyani Steel Industries, Koppal, Karnataka was separated from fines, the coarser fraction was tested in similitude with conventional aggregates. It is to be noted here that as per IRC guidelines for WBM refer Table 1.2, passing 11.2mm IS sieve is treated as fines and fraction retained on 11.2mm IS sieve is taken as coarse.

Sl.No.	Parameter	IS code	Obtained value	Prescribed limits asper MoRD &IRC: 19-2005
1	Impact value of aggregate	IS:2386Part 4	25%	< 30%
2	Los Angeles abrasion value	IS: 2386Part 4	14%	< 40 %
3	Flakiness index	IS:2386Part 1	1%	< 15%
4	Water absorption	IS:2386Part 3	1.12%	<10%
5	Crushing value of aggregates	IS:2386Part 4	26.93%	<30%
6	Specific Gravity	IS:2386Part 3	3.52	
7	Angularity number	IS: 2386Part 1	13	
8	Bulk density	IS:2386Part 1	17.55 kN/m^3	>11.20 kN/m^3
9	Soundness	IS:2386Part 5	0.8%	< 18%(Magnesium Sulphate)

H. *Properties of Soil*

Soil for present study was collected from Davangere, Karnataka. Since soil is being used as a binder in the present study, it essential that it conforms to liquid limit and plasticity index values prescribed in IRC code refer Table 1.6. Before conducting test soil was pulverised, cleaned and air dried.Apart from basic tests like natural water content, specific gravity, particle size analysis, liquid limit and plastic limit; Compaction test and California Bearing Ratio (CBR) test were also conducted on soil.

TABLE III
PROPERTIES OF SOIL

Sl. No	Property	IS code	Obatined value	Prescribed limits as per MoRD&IRC:19-2005
1.	Specific gravity	IS:2720 Part 3	2.23	
2.	Natural water content	IS: 2720 Part2	5.13%	
3.	Particle sizeanalysis CuCc	IS: 2720 Part4	6.07 0.71	
4.	Liquid limit	IS: 2720 Part5	40.50%	<55
5.	Plasticity Index	IS: 2720 Part5	16.36%	<30
6.	Maximum Dry Density	IS: 2720 Part8	1.57 g/cc	
7.	Optimum Moisturecontent	IS: 2720 Part8	24.3%	
8.	CBR	IS: 2720 Part16	3%	
9.	Colour	IS:2720 Part 3	Black	

I. Tests on Water bound macadam (WBM)

In the present study WBM is evaluated as a wearing course of a low volume rural road with less than 1MSA traffic and assuming arid climatic conditions with average annual rainfall less than 25cm. As WBM is being used as wearing course, as per IRC: SP: 20-2002 recommendations, Coarse aggregates of Grade-3 and Screenings of Type-B are used.Following three experiments are conducted on WBM-A and WBM-B

a) California Bearing Ratio (IS:2720 Part16)
b) Rutting Tests using Roller Compactor cum Rut Analyser (RCRA)

J. California bearing ratio(CBR) Test

In order to ascertain the strength and stability of WBM CBR test is carried out. CBR test consists of preparation of specimen, soaking and conducting penetration test.

Dimensions of cylindrical mould are measured to know the volume of specimen to be prepared. Quantities of coarse aggregates, screenings and binder required for each specimen of given area and thickness is calculated by interpolating from values given in IRC:19-2005 for 10m2 area and 75mm compacted thickness in a similar manner as that of compaction test.

All constituents were weighed and mixed with water corresponding to OMC as obtained from compaction test. Material was compacted in 5 layers with 56 blows each; with the surcharge in place it was soaked in water for 4 days. After which penetration test was conducted to note the load required to cause 2.5mm and 5.0mm penetration, CBR is expressed as percentage of ratio of these loads to standard loads at corresponding penetration depth as per IS:2720 Part-16 guidelines.

K. Rutting test using Roller compactor cum rat Analyser

In the present study since WBM is being studied as a wearing course, as per IRC:19-2005 the compacted thickness adopted is 75mm. By placing wooden planks at the bottom of mould required depth is made available as original depth of mould was higher. Width and length of mould are noted to compute area. The volumes of coarse aggregates, screenings and binder required for given area are obtained by interpolating volumes given in IRC: 19-2005 for 10m2 area.RCRA mould is properly cleaned and it's inside surface is properly lubricated. RCRA has provision to mount either compacting wheel or rutting wheel to the same frame. Initially for compacting purpose compacting wheel is mounted. Coarse aggregates are placed and spread uniformly in the mould, followed by rolling. After a certain period of time rolling is stopped, screenings are applied over this coarse aggregate layer with light application of water and rolling is resumed. Rolling continued till thickness achieved is in excess by around 5mm of required 75mm thickness. Rolling is stopped, with aid of water binder (soil) is uniformly applied over the surface and compacted to required 75mm thickness. This compacted surface is left for few hours to set/dry properly.Compacting wheel is dismounted from frame and rutting wheel is fixed to carry out rutting test on the surface. The level of the finished surface is accurately marked and noted; rutting wheel is made to operate on the surface with application of required pressure. Rut depth is measured at regular intervals of 5 passes of rutting wheel with finished surface after compaction as datum. This is continued until a rut depth of 20mm is reached.

Figure 1: Compaction and rutting using RCRA

Table 4: Different combinations of WBM for testing

Sl.No	Designation	Coarse aggregates	Screenings	Binder
1	WBM-A	Conventional aggregates	Steel slag (fines)	Soil
2	WBM-B	80% conventional aggregates + 20%steel slag(coarse)	Steel slag (fines)	Soil

IV Result & Discussion

Results of various tests conducted on WBM are discussed in this chapter. It should be noted that in all three tests i.e. Compaction, CBR and Rutting test Grade-3 for coarse aggregates and Type-B for screenings is adopted as per IRC: 19-2005 guidelines for WBM as wearing course.

Before conducting various tests, bulk density of conventional aggregates is determined as 1550 kg/m3 and that of 80%conventional aggregates+20% steel slag (coarse) as 1588 kg/m3. Steel slag (fines) screenings weighed 1950 kg/m3 whereas binder (soil) weighed 1570 kg/m3 at its OMC. These values are of prime importance in calculating quantities of materials for tests.

Results of Rutting Test

Rutting tests performed on WBM-A and WBM-B at two different tyre pressures [2] [10]of 5.6 kg/cm2 and 6.2 kg/cm2 are compared below in plates 4.8 and 4.9 respectively.

Table5:RuttingCharacteristicsat5.6kg/cm^{2}TyrePressure

Tyre Pressure 5.6 kg/cm^2	WBM-A	WBM-B
No. of Passes for 20mm Rut Depth	82	97

Table6:RuttingCharacteristicsat6.2kg/cm^{2}TyrePressure

Tyre Pressure 6.2 kg/cm^2	WBM-A	WBM-B
No. of Passes for 20mm Rut Depth	72	78

V. CONCLUSIONS

Based on the present study following conclusions can be drawn.

1. Both Maximum Dry Density(MDD) and California Bearing Ratio (CBR)ofWBM increased with partial replacement of conventional mineral aggregates by steel slag (coarse).

2. Replacement by steel slag (coarse) could not yield higher improvements as that in case of compaction and CBR in resistance against rutting.
3. With increase in tyre pressure there is decrease in rutting resistance, 13% reduction was noticed in case of WBM with conventional aggregates and 18.58% reduction in case of WBM with partial replacement by steel slag (coarse).
4. Partial replacement of steel slag resulted in 18.30% and 8.33% rise in rutting resistance of WBM compared to conventional aggregates at 5.6kg/cm2 and 6.2kg/cm2 tyre pressures respectively, Also 10% and 70% increase in MDD and CBR of WBM.

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