International Journal of Advance Research in Science and Engineering
Vol. No.5, Issue No. 04, April 2016
www.ijarse.com
IJARSE
ISSN 2319 - 8354

UTILIZATION OF COPPER SLAG AND STONE DUST IN BITUMINOUS PAVEMENT WITH HYDRATED LIME AS FILLER MATERIAL

Somnath Singh[1], Dr. A.K. Mishra[2]

[1] P.G. Scholar, [2] Assistant Professor, Civil Engineering Department,
M.M.M. University of Technology, Gorakhpur, U.P.(India)

ABSTRACT

In this paper an attempt has been made to utilize the copper slag and stone dust as fine aggregate and hydrated lime as filler in flexible pavement. Copper slag is an industrial by product produced in country as waste material. Copper slag is generated during the extraction of metal from its ore. Since copper slag is a non-plastic coarse grained material having high CBR value up to 70% and good permeability so it has the potential for utilization as partial replacement of conventional fine aggregate in bituminous mixes like BM, DBM, SDBC , BC. Marshall test has been carried out for the purpose of mix design and evaluation of paving mixes. The Marshall properties like stability, flow value, % air voids, VMA, VFB and optimum bitumen content was determined.

Index Terms:* *Bitumen, Copper slag, Stone dust, Marshall Mix design

I. INTRODUCTION

In India there is a huge quantity of naturally available materials like aggregates are being utilized for road constructions. The constructions of roads for national highways, state highways and development of several expressways have created tremendous pressure on natural resources. There is a thrust to calibrate the feasibility of local soil and industrial waste materials to replace the conventional construction materials [1-4]. These studies try to contest the society's need for economic disposal and safe of waste materials with the highway industry's required better and more cost-effective construction materials.

This research aims to explore the potential use of copper slag (CS) as a replacement of conventional fine aggregate in the design of bituminous like Bituminous Macadam (BM) Semi-Dense Bituminous Concrete (SDBC), which upgrade the property of the bituminous mixes [1].

II. PRELIMINARIES

2.1 Non-ferrous Slag as Construction Material

Nonferrous slags are produced during the recovery and processing from non-ferrous materials. The slags are molten by-products of high temperature conditions that are primarily used to divide the metal and nonmetal constituents contained in the bulk ore. When cooled, the molten slag converts to a rock material or granular material. The processing of most ores involves a series of standardized steps; the bulk ore is processed to clear any gangue. This treatment typically consists of pulverizing the ore to a relatively fine state, followed by a few form of gravity separation of the metals from the gangue, using a series of devices including cyclone divider, inclined vibratory tables, and flotation tanks. Since most of these metals are unsuitable for use in a pure state, they are finally combined with other elements and compounds to form alloys having the desired properties. In determination for metal ion reduction, some non oxide minerals are often converted to oxides by heating at air temperatures below their melting point [7]. Sulphide minerals, when present in copper, are converted to oxides. In this process, a reducing agent, such as impure carbon, along with CO and H2, is combined with the roasted product and melted in a siliceous flux. The metal is finally gravimetrically separated from the composite flux, leaving the residual slag.

CS is produced by (Fig. 1): (i) Scalding, in which sulphur in the ore is knock out as sulphur dioxide (SO2); (ii) Smelting, in which the scalded product is melted in a siliceous flux and the metal is reduced; and (iii) Converting, where the melt is de sulphurized with lime flux, iron ore, or a basic slag and then oxygen lanced to remove other impurities. CS is derived by smelting of copper concentrates in a reverberatory furnace is referred to as reverberatory CS [6]. Approx 4 million tons of CS is produced each year in the US while in India production is about 10 lakh tons/annum utilization in Highway Construction [2]

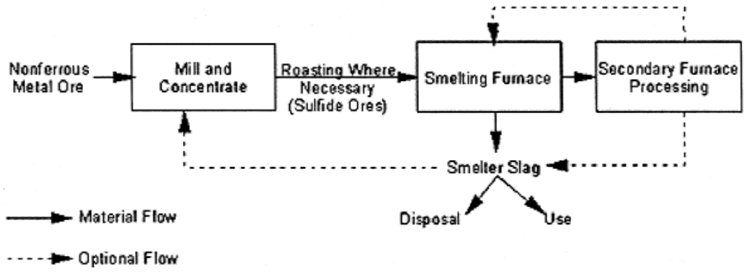

Fig. 1 General process diagram for copper slag production [2]

Table 1 — Properties of aggregates and CS

Properties	Unit	Method of test	Test value
Properties of coarse aggregate			
Bulk specific gravity	--	IS: 2386(I)	2.68
Apparent specific gravity	--	IS: 2386(I)	2.72
Impact Value	%	IS: 2386(IV)	18
Flakiness and Elongation (combined) Index	%	IS: 2386(I)	40
Stone polishing Value	%	BS: 812(114)	60
Soundness with sodium sulphate	%	IS: 2386(Part-3)	2
Water absorption	%	IS: 2386(Part-3)	0.5
Stripping	%	IS: 6241	5.0
Water sensitivity by Tensile Strength Ratio (TSR)	%	AASHTO-T-283	>80

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ISSN 2319 - 8354

Properties of fine aggregate			
Bulk specific gravity	--	IS: 2386(I)	2.68
Apparent specific gravity	--	IS: 2386(I)	2.72
Angularity Number	--	IS: 2386(I)	49
Plasticity Index	--	IS: 2720	NP
Properties of lime			
Bulk specific gravity	--	IS: 2386(I)	2.80
Surface area	m^2/kg	---	59
Copper slag			
Unit weight,	kg/m^3	IS: 2386(I)	2800 to 3800[15]
Absorption	%	IS: 2386(Part-3)	0.13

TABLE 1 [3]

Property	Analysis
Hardness, Moh's Scale	6 – 7
Specific Gravity	3.51
Plasticity Index	Non-Plastic
Swelling Index	Non-Swelling
Granule Shape	Angular, Sharp edges, Multifaceted
Grain Size Analysis	
Gravel (%)	1.00
Sand (%)	98.90
Silt + Clay (%)	0.05

(Ref. Birla Copper Unit, Hindalco's Industries Ltd, Dahej, Gujarat, India)

Table 2

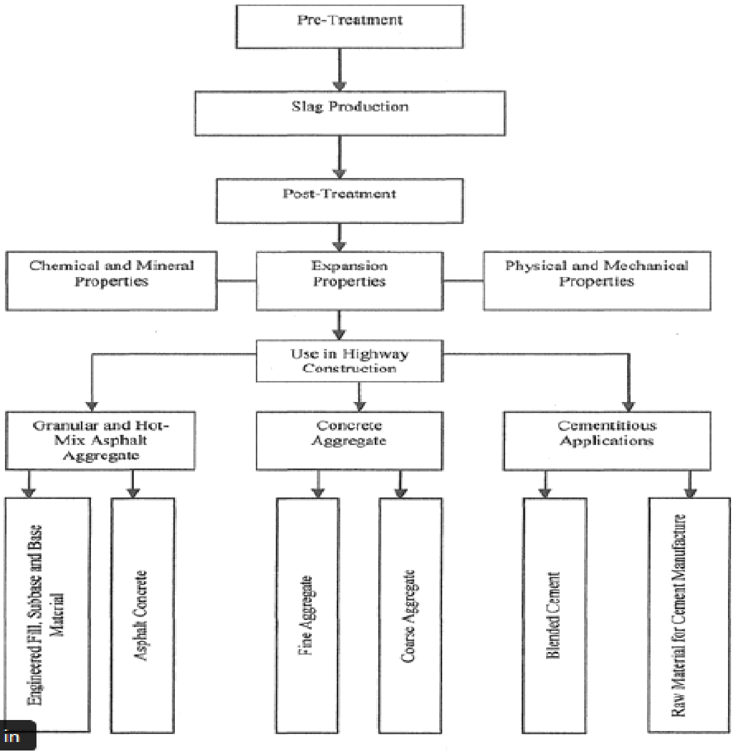

Fig. 2 Overall process of slag

III. METHOOLOGY

3.1 Laboratory Investigation

BM is base course layers, and the wearing courses are BC & SDBC of Flexible Pavement Construction. This investigation aims to use CS in bituminous road construction as construction material. In India, no mix design procedure is available till date for open graded mixes like BM, which has a tendency to break at 60ºC because of more open texture. Since, BM is used as a base course layer below the wearing course and it may be logical that the stability at temperature be lower than 60ºC. Therefore, the testing temperature was included at 60 ºC [8], [9]

3.2 Marshall Method of Mix Design

Marshall Mix design was carried out as per ASTM D 69277 (2006) to determine the mix proportion and OBC for BM and SDBC. There are two major features of Marshall Method of mix design. (i) Density void analysis and (ii) stability flow tests.

3.3 Aggregates

Stone aggregates, play a major role in road construction, bear load due to particle bonding and sustain wear and tear due to vehicular movement. The acceptability limits(7-9) depends upon the type of construction (Table 1). Gravel was used as coarse aggregate (20 mm and 10 mm), CS and stone dust as fine aggregate and hydrated lime as filler material. CS is a black, glassy and vesicular matter (unit wt. 2800-3800 kg/m3, water absorption 0.3% having common specific gravity lies in the range 2.8-3.8).

3.4 Bitumen

Bitumen is basically a mixture of hydrocarbon and thermoplastic material having strong tarry odour. Elementally, it consists 95% carbon and hydrogen (± 87% carbon and ± 8% hydrogen), and up to 5% sulfur, 1% nitrogen, 1% oxygen and 2000ppm metals. Bitumen are composed mainly of highly condensed polycyclic aromatic hydrocarbons. Three basic types of bitumen are (i) Asphaltene, (ii) maltene, and (iii) Carbene [10]. Asphaltene is hard and aromatic. Maltene is a solvent and force visco elasticity to bitumen. It is resin like intermediate molecule of hydrocarbon. Carbene is the fraction, which is insoluble in carbon tetrachloride. Bitumen as a material has drawn attention to the engineers since a past time because it is (i) water proof, (ii) durable, (iii) resistance for strong acids, and (iv) possesses good cementing properties.

At medium temperature, it is a thermoplastic semi-solid cementing material and at higher temperature, bitumen shows like a viscous liquid, whereas at a very low temperature bitumen is brittle in nature as glass. Bitumen is initiating to behave visco elastically at the standard operating temperatures of highways. The type of bitumen penetration grade for this study was VG 10 usually used as a Paving Grade Bitumen appropriate for formation of flexible pavements with superior properties [6].

Characteristics	Method of Test	Test Results
Specific Gravity	IS1202:1978	1.09
Softening Point (℃)	IS1202:1978	52
Penetration25℃ (mm)	IS1202:1978	92
Ductility	IS1202:1978	85

Table 3

3.5 Proportion of Aggregates

Aggregate gradation is the most important properties in bituminous mixture, which affects completely all the important properties like stability, durability, workability and resistance for moisture damage. Therefore, gradation is the primarily consideration of bituminous mix design. The typical aggregate gradation taken for the design of BM and SDBC are as per the MORTH Specification [9] in order to explore the potential use of Copper Slag as fine aggregate in optimum level which explain the property of the mixes to get the final grading (Tables 3 & 4) [7].

3.6 Determination of Optimum Binder Content

At each grading, Marshall Samples were assembled by varying the binder content and tested for its volumetric properties.

3.7 *Significance of Volumetric Parameters*:

Bitumen holds the aggregates at conditions and the load is taken by the aggregate mass through the contact points. If complete voids are filled by bitumen, load is exerted by hydrostatic pressure through bitumen, and strength of the mix,

Type of mixes	Size of aggregate		Ingredients, %		
	20 mm	10 mm	Copper slag	Stone dust	Lime
BM	38	37	10	15	-
SDBC	-	60	20	17	3

TABLE4 [4]

Therefore, reduces. That is why stability of the mix starts decreasing when bitumen content is increased beyond some value. Also during summer season, bitumen melts and occupies the void space among aggregates and if the voids are not available, bitumen causes bleeding. An amount of void is quite necessary in a bituminous mix, even after the final stage of compaction. For obtaining of optimum binder content (OBC), the data of bulk density, stability and air voids are plotted between the binder contents (Figs 2-5) [3].

3.8 Selection of Optimum Bitumen Content (OBC)

OBC is delicate a balancing act in which there are a number of variables – such as voids in mineral aggregate , air voids , and voids filled with bitumen. A balance is to be fostered such that all the specification limits recommended in the code of practice are equivently satisfied. OBC for different mixes was found as follows: BM, 3.5; SDBC, 5.5 % [4].

Optimum Binder Content		
Property	BM	SDBC
Binder % by mix	3.5	5.5
Bulk density, g/cc	2.36	2.50
Air voids, %	9.77	4.29
VMA	17.38	16.735
VFB, %	43.78	74.317
Stability, kg	1262.6	1430
Flow, mm	4.75	3.5

3.9 Marshall Mould

The aggregates of various grades were sieved through various IS Sieves and they were kept in various containers with proper marking. The mixing of materials required for mould formation was done as needful quantities of coarse aggregate, fine aggregate & mineral fillers were taken in an iron container. The mix was kept in an oven at temperature 160 °C for 2 hours. This is due to the aggregate and prepared blends are to be mixed in warmed state so preheating is required. The prepared blend was also heated up to its melting point before to the mixing .The aggregates in the container kept in oven were taken and heated on a controlled gas stove for hardly a minutes holding the temperature. Now mix (60 gm.), i.e. 5% was added to this mix and the whole blend was mixed uniformly and homogenously. This process was continued for 15-20 minutes till they were properly mixed. Then the blend was moved to the Marshall sampling mould. The blend in the mould was then compacted by the Marshall Hammer, 75 numbers of strokes were given on all sides of the sample so a subtotal of 150 numbers of strokes was given per sample. Then we kept these samples with mould individually and then we marked the samples consequently to the percentage of polythene added by weight of bitumen [9].

Fig. 3 Marshall Apparatus

Sieve Sizes	Adopted grading for bituminous as per MORTH specification	
37.5	100	100
26.5	100	100
19	99	99
13.2	67	81
9.5	59	76
4.75	25	46
2.36	18	37
1.18	11	23
0.600	5	-
0.300	3	9
0.150	3	-
0.075	3	3

Table 5

IV. RESULT AND DISCUSSION

By addition of CS, the density of bituminous mixes at OBC is as follows: BM, 2.273; SDBC, 2.541g/cc. The higher densities are because of the good bonding developed by the fusion of CS as fine aggregate in the bituminous mixes. The Marshall stability is a measure of the strength of a bituminous mixes. Greater will be the strength of surfacing and higher the stability of the mix,. BM at 40° C are the stability values and that of other bituminous mixes SDBC at 60° C are 1429 kg respectively at OBC.

A. Parameter obtained for SDBC

% of Bitumen	V_v	V_b	VMA	VFB	MSV	Flow Value
4%	4.45	9.21	13.66	67.41	1230	2.375
4.5%	4.40	10.27	14.87	69.10	1269.23	3
5%	4.36	11.37	15.74	72.28	1346.15	3.25
5.5%	4.30	12.44	16.74	74.32	1430	3.5
6%	4.26	13.48	17.74	75.98	1384.61	3.75

Table 7

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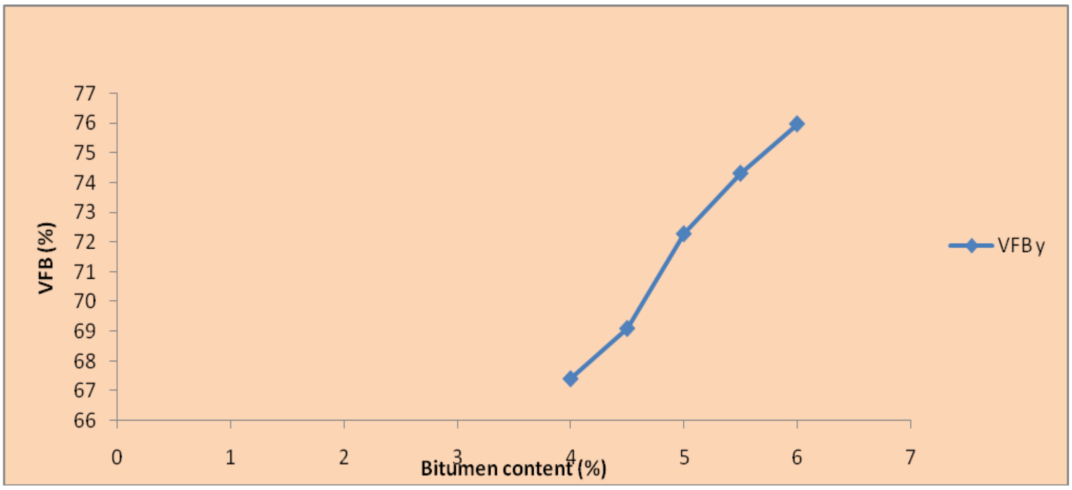

Fig. 4 Variation of VFB % at different Bitumen content

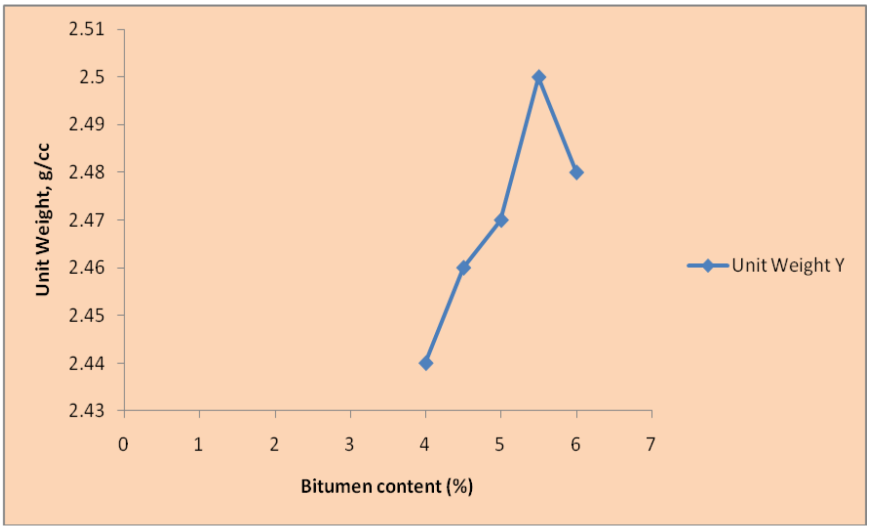

Fig. 6 Variation of Unit Weight g/cc at different Bitumen content

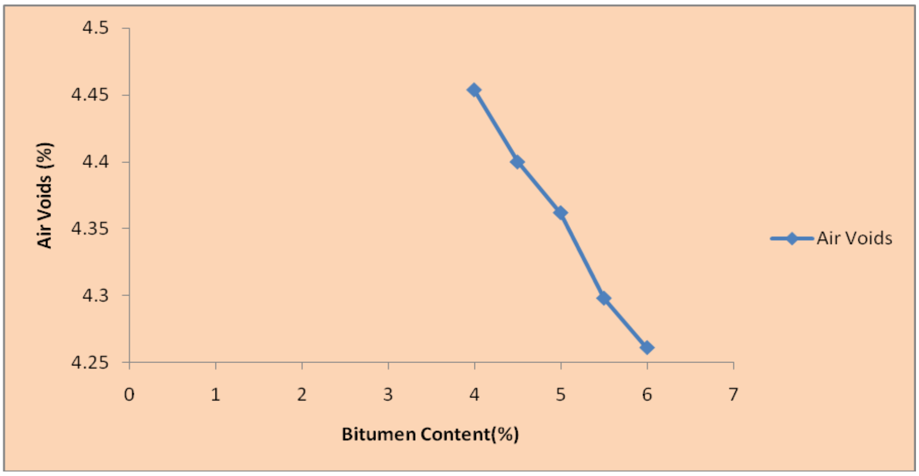

Fig. 5 Variation of Air Voids % at different Bitumen content

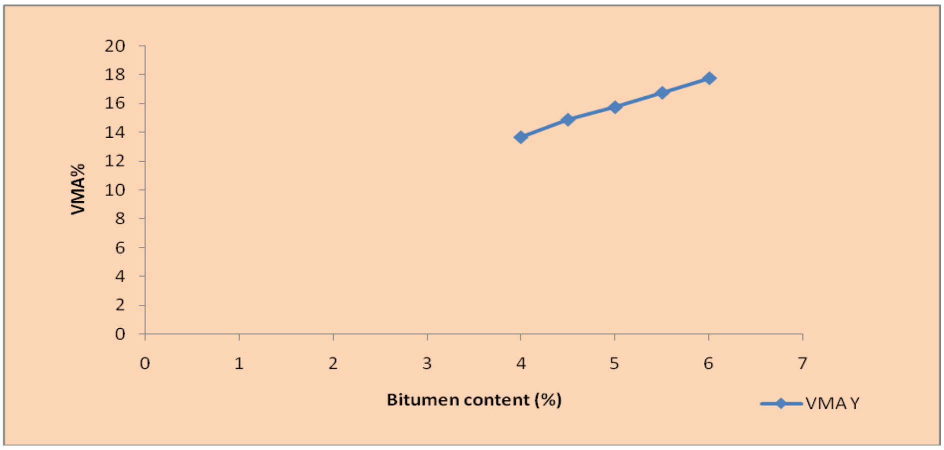

Fig 7 Variation of VMA % at different Bitumen content

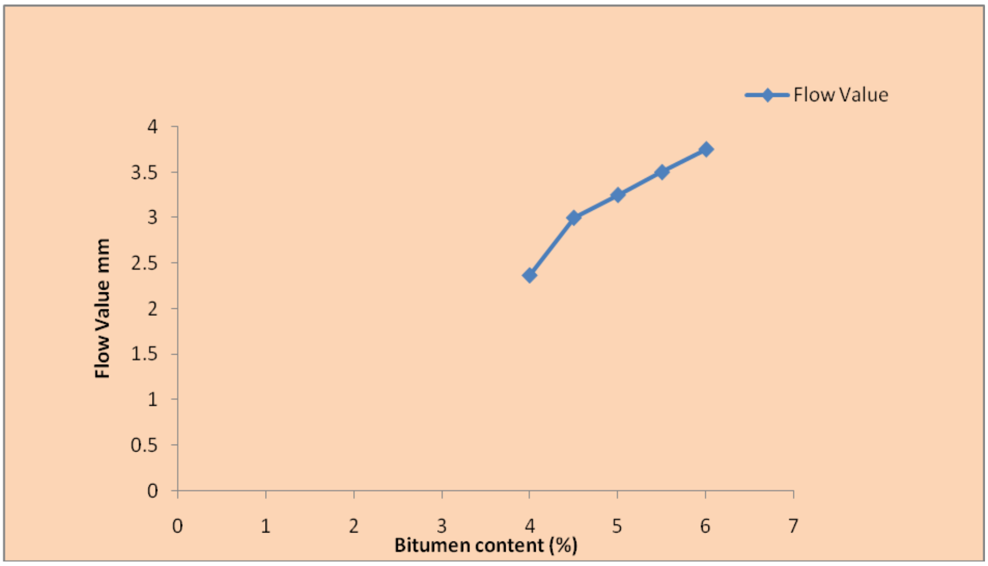

Fig. 8 Variation of Flow value at different bitumen content

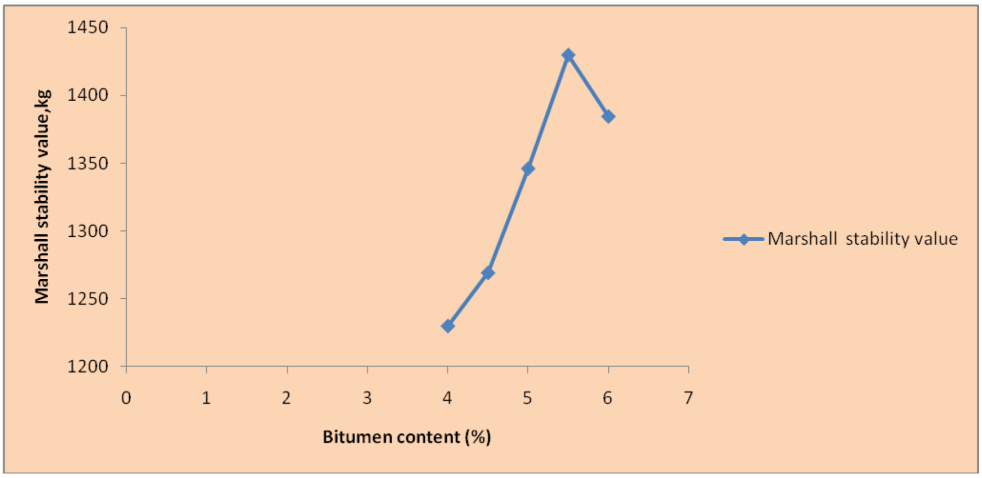

Fig. 9 Variation of MSV at different Bitumen content

B. Parameter obtained for BM

% of Bitumen	V_v	V_b	VMA	VFB	MSV	Flow Value
2.9%	10.67	6.32	16.99	37.19	1244.4	3.75
3.1%	10.43	6.74	17.17	39.25	1258.4	4
3.3%	10.01	7.19	17.20	41.80	1285.2	4.5
3.5%	9.77	7.61	17.38	43.78	1262.6	4.75
3.7%	9.44	8.05	`17.49	46.02	1220.2	5.25

Table 8

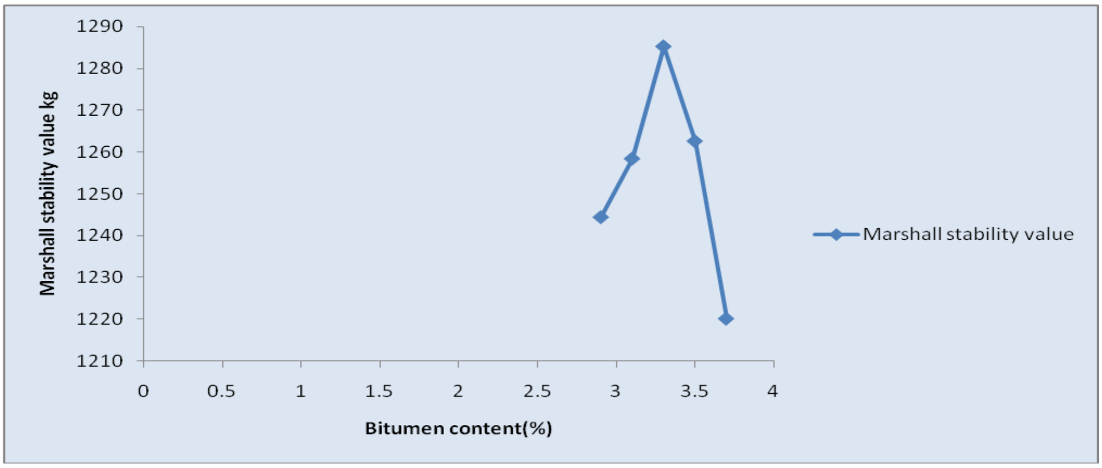

Fig. 10 Variation of Marshall stability value kg at different bitumen content

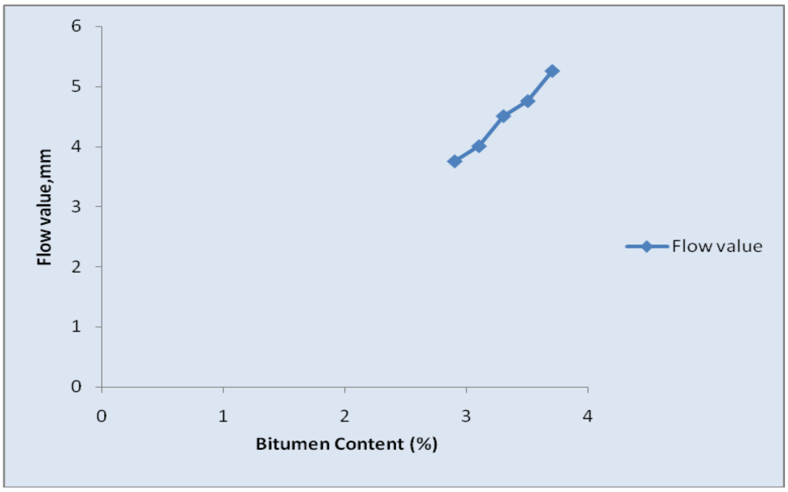

Fig. 11 Variation of Flow value at different bitumen content

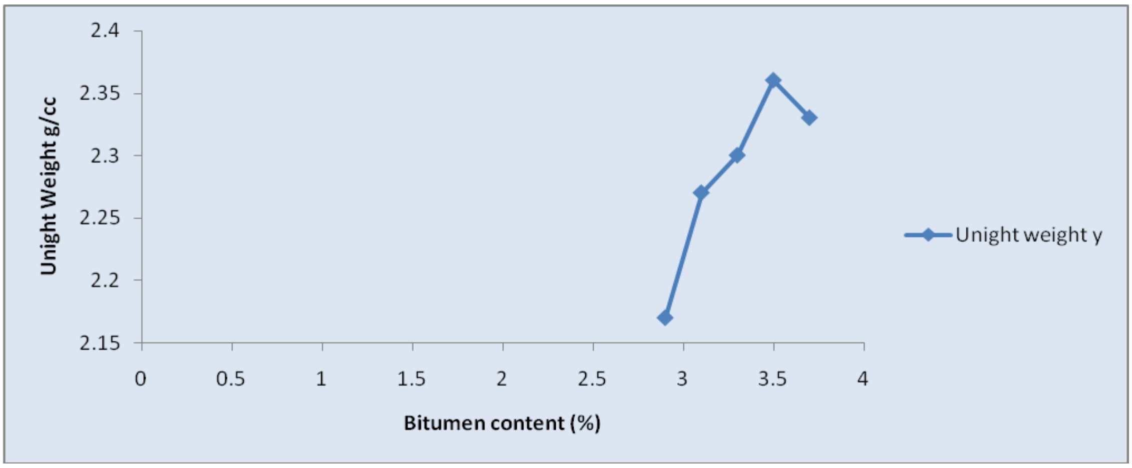

Fig. 13 Variation of Unit weight g/cc at different bitumen content

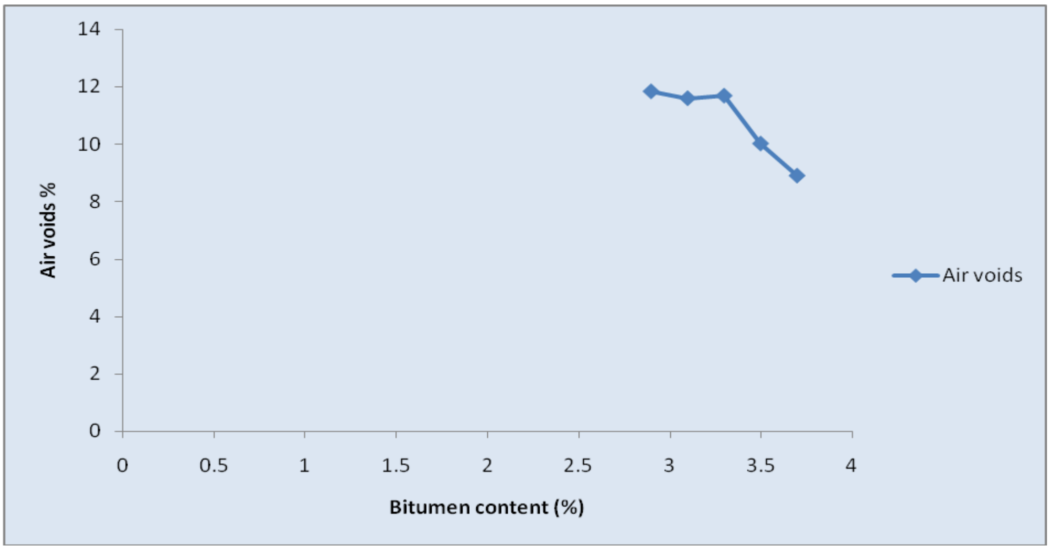

Fig. 12 Variation of Air voids % at different bitumen content

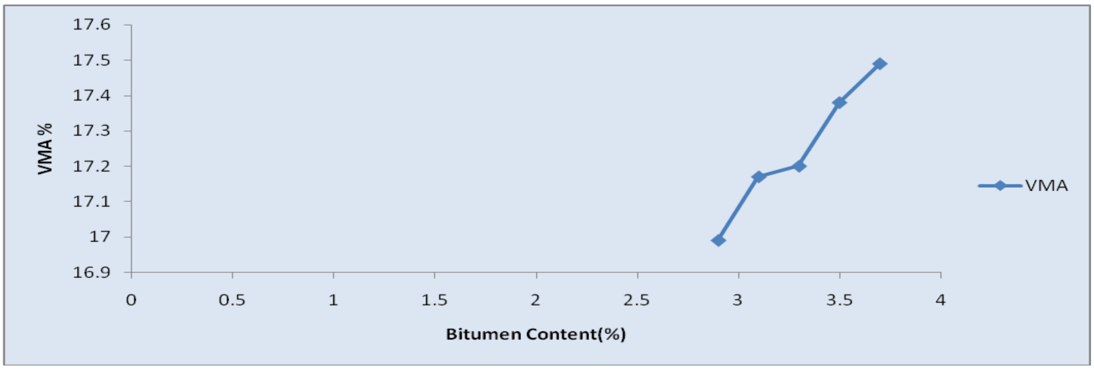

Fig. 14 Variation of VMA % at different bitumen content

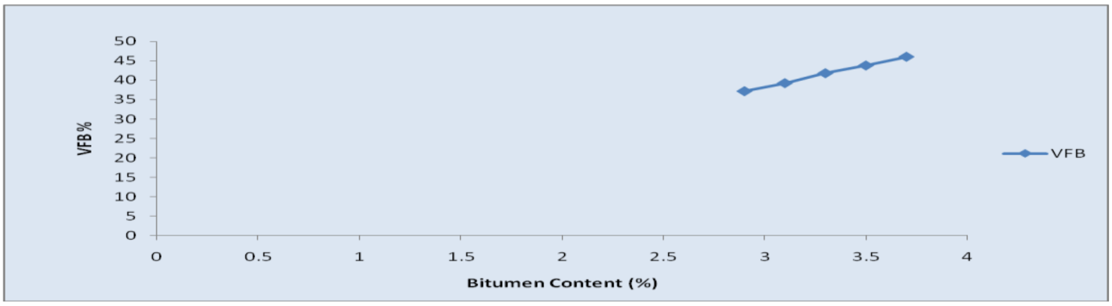

Fig. 15 Variation of VFB % at different bitumen content

V. UNITS

Here

- g/cc represent gram per centimeter cube
- kg represents kilogram
- M represents the unit of meter.

VI. HELPFUL HINTS

C. Figures, Table and Notations

Figures

- Figure 1 represents General process diagram for copper slag production
- Figure 2 represents overall process of slag utilization in Highway Construction
- Figure 3 represents Marshall Apparatus
- Figure 4 Variation of VFB % at different Bitumen content
- Figure 5 Variation of Air voids % at different Bitumen content
- Figure 6 Variation of Unit weight g/cc at different bitumen content
- Figure 7 Variation of VMA % at different Bitumen content
- Figure 8 Variation of Flow value at different Bitumen content
- Figure 9 Variation of Marshall stability value at different Bitumen content
- Figure 10 Variation of Marshall stability value at different Bitumen content
- Figure 11 Variation of Flow value at different Bitumen content
- Figure 12 Variation of Air voids % at different Bitumen content
- Figure 13 Variation of Unit weight g/cc at different Bitumen content
- Figure 14 Variation of VMA % at different Bitumen Content and Unit weight
- Figure 15 Variation of VFB % at different Bitumen content

Table

- Table 1 represents properties of Aggregate and CS
- Table 2 represents properties of Copper slag
- Table 3 represents properties of Bitumen

- Table 4 represents % in gradient of mix
- Table 5 grading of Bitumen as per Morth Specification
- Table 6 represents OBC for SDBC and BM
- Table 7 represents parameter obtained for SDBC
- Table 8 represents parameter obtained for BM

Notations

- CS represents Copper Slag
- BM represents Bituminous Macadam
- SDBC represents Semi Dense Bituminous Concrete
- OBC represents Optimum Binder Content
- VFB represents voids filled with bitumen.
- VMA voids in mineral aggregate
- VA represents air voids

VII. CONCLUSION

It was concluded that we can improve the interlocking property of bituminous mixes like BM & SDBC by using copper slag & stone dust. Addition of copper slag as fine aggregate in different bituminous mixes provides good alternative of conventional aggregate. The amount of replacement of CS & stone dust may vary from 10-25% in BM and SDBC. The results showed that the Flow value, VMA, VFB increases with increases in Bitumen content ranging from 2.9- 6 % in BM & SDBC.As we know copper slag is an industrial waste, use of it can successfully avoided the disposal problem upto certain extant. Because of higher specific gravity of CS as compare to natural aggregates the bulk density increase with addition of CS.

VIII. ACKNOWLEDGMENT

This work has been carried out in civil engineering department of Madan Mohan Malaviya University of Technology, Gorakhpur, India. The author presents its heartiest gratitude towards Dr. A.K. Mishra for constant encouragement, guidance and support.

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