International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 11 | Nov - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Optimization-Based Study on the Use of Granulated Copper Slag in Bituminous Base Layers

[1]Dr. M. MADHURI, [2]KAMPARA VIJAYA

[1] Associate Professor& HOD, [2] PG Student

[1,2] Department Civil Engineering

Sanketika Vidya Parishad Engineering College, Visakhapatnam, Andhra Pradesh

---

Abstract -Industrial waste generation has increased significantly in recent decades, creating major environmental and land management challenges. Among these wastes, Granulated Copper Slag (GCS) from non-ferrous metallurgical industries is produced in extremely large volumes, with the copper industry generating 99% waste for every 1% metal recovered. This study focuses on evaluating the suitability of GCS as an alternative fine aggregate in bituminous pavement layers, aiming to promote sustainable material utilization and reduce dependence on natural aggregates. The research involves detailed chemical characterization, physical property evaluation, environmental safety assessment, and mix design optimization of GCS for use in Copper Slag Dust Base (CSDB) layers. Chemical analysis shows that GCS contains 43% iron, 34.9% silica, and only trace amounts (<1%) of potentially hazardous elements such as cadmium, arsenic, cobalt, and lead. Toxicity Characteristic Leaching Procedure (TCLP) results confirm that all leached metals fall well within EPA regulatory limits, indicating that GCS is safe for pavement use. Physical property comparison further shows that GCS satisfies ASTM D1073 and AASHTO M29 requirements for fine aggregates. To determine optimum usage, seven GCS–quarry dust combinations were evaluated using Grading Index (GIc) values ranging from 0.20 to 0.80, corresponding to GCS contents varying from 20% to 80%. Mix design trials were conducted using 80/100 grade bitumen at binder contents of 4.5%, 5.0%, 5.5%, and 6.0%, compacted with 75 blows per side as per Marshall standards. The resulting CSDB mixes exhibited acceptable stability, air voids, VMA, VFB, and flow characteristics across multiple GIc combinations. Optimization revealed that mixes with 40–67% GCS (GIc = 0.40 to 0.67) provide the best balance of strength, workability, and specification compliance, enabling high-volume utilization without compromising performance. Overall, the study demonstrates that GCS can be effectively incorporated as a sustainable aggregate alternative in bituminous base layers. Its chemical safety, favorable physical characteristics, and successful performance in CSDB mix designs confirm its potential for large-scale application in flexible pavement construction.

***Key Words*: GCS, Bituminous layers, Copper slag dust base, Mix design, Marshall stability**

1.INTRODUCTION

In the recent years, waste management has become a challenge for human community due to abundant growth of industries. The rapid industrialization has brought deterioration in the quality of our environment by generating large quantities of solid waste. The metallurgical industries are among the worst offenders in terms of environmental degradation. Utilization of solid waste is a matter of concern for the society. The accumulation of bye- products poses a threat to the environment and occupies prime land near industries. The safe disposal of solid waste is now becoming a primary function of the industries. It has been observed that some of these wastes have hazardous metal concentration in it. These metal wastes require safe disposal in order to avoid possible environmental pollution.

A few waste materials can be effectively utilized for highway construction, as they possess many desirable engineering properties. By using the waste materials as an alternative to the fine or coarse aggregates, the natural stone reserves could be preserved. Utilization of industrial wastes for the construction of highway pavements could solve the problem of environmental pollution and pave way for the bulk disposal.

Presently large-scale road projects are in progress in India at a huge capital cost to create an atmosphere for global investments in the industrial and other sectors. The National Highways Development Project (NHDP) and Pradhan Mantri Grama Sadak Yojna (PMGSY) are the major road projects planned with an investment of about Rs.300 billion per year (Sharma 2006).

In view of enormous road construction activities in the country, which consumes substantial quantum of aggregates, there is a need to develop an alternative material for sustainable road development. Construction of road is cost intensive and the material cost alone is more than 50% of the total construction cost (Indian Highways Editorial, May 2009). Of this, stone aggregate, the major component, constitutes about 60% of the material cost. Considering the vast impact on economy and environment, demand and supply, the availability of waste materials like fly ash, pond ash, copper slag, plastic waste, etc., has to be explored as an alternative material along with their properties and possible use in the road construction. Since each of the structural layers of a road is expected to perform certain functions, the materials used are also expected to fulfill certain requirements as stipulated in the standards. Hence, it is important to economize in construction with proper selection of materials, optimum input of technology and adoption of appropriate design methodology by conducting extensive research in order to attain sustainability in the highways sector.

India is a developing country, having a variety of industries. The wastes generated from petrochemical, chemical and mineral processing industries, etc., account for nearly 150 mt per annum. Out of the listed industries above, the mining and metallurgical industries generate more hazardous waste than the other industries. Indian non-ferrous industry has been registering considerable growth during the past decades. The present economic scenario in the country is highly conducive to all-round growth and development of non-ferrous industry. The solid waste generated and recoveries of metals from selected non-ferrous industries are shown in Table 1.1.

Table1. Waste Generations and Recovery of Metals

Sl. No	Non-Ferrous Metal Industries	Solid Waste Generated	Waste as %of Ore Extracted	Recovery of Metals in%
1	Aluminum	Red mud sludge And Spent pot lining	77	23
2	Copper	Smelter and converter slag, Leach residues	99	1
3	Lead	Smelter slag, Dresses and scrap	96	4

(Source:WorldWatchInstituteReport1992,Sinhaetal.1998)

From the above table, it may be inferred that to generate a little quantity of usable metals, the waste generated is very high. Especially in the copper industry, wastage is higher than the other industries. Hence, the waste generated from the copper industry must be examined for its effective utilization.

The copper industry is one of the major developing industries in India. The domestic production of copper is about 0.50 mt per annum whereas the demand is about 2.50 mt (Sinha et al.1998). From this, it is evident that a huge deficit of about 2 mt per annum has induced the industries to enhance the capacity of production.

The objectives of the study are:

- to identify environmental considerations and technical characteristics of GCS as an aggregate in bituminous base.
- to evolve a methodology for arriving at specification for Copper Slag Dust Base (CSDB) with an objective of high-volume utilization.

2. LITERATUREREVIEW

The literature available on copper slag is very limited. The copper slag was used as an abrasive material by exploring its silicon properties (Szyrle and Wzniak 1988). It has been explored that the copper slag can be used as an abrasive material form a chining non-ferrous metals, wood or plastic. Herman (1989) investigated the usage of copper slag as a ceramic raw material in ceramic binder and found that the mechanical properties were improved when the copper slag was added into ceramic abrasive tools.

The slag contains some concentration of metals in the ores from which they were produced (Collins and Miller 1979). Adding copper slag as a substitute for Portland cement has shown to have a significant influence on increasing the compressive strength of concrete mixes (Mobasher et al. 1996). Some non-ferrous slag has been used in concrete mixtures and as rail road ballast. GCS has been used as a bridge blasting abrasive (Appleman 1992). Copper slag hasbeen used for mine backfill and granular materials (Asokan Pappu et al. 2004). The main use for copper slag in Australia is in grit blasting due to its sizing and strength characteristics (www.asc-inc.org.au).

Waste materials can be used for construction of low-volume roads with twofold benefits; (a) it will help clear valuable land of huge dumps of slag, and (b) it will also help preserve the natural reserves of aggregates, thus protecting environment (Sudhir et.al 1999). In India, the usage of copper slag in pavements is very limited and unexplored. The laboratory investigation for replacing the fine aggregates with GCS has been carried out by Central Road Research Institute (CRRI) and recommended about 20-30% usage in dense bituminous mixes (Nanda2006). The use of copper slag in the sub base as a Component in the mixture of fly ash and soil has been tested and reported (Vasant et al. 2007).

The mix considerably includes aggregate characteristics. The aggregates are the major components of bituminous mix. Only about 5-7% (in major base and surface course mix bituminous mix designs) bitumen is used in bituminous mixes. The balance of about 90-95% of the mix is of aggregate portion. Current literature on the development of aggregate grading for open graded and dense graded mixes show that the design considerations are to produce blends that give maximum density in case of dense graded mixes and voids considerations in case of open graded mixes.

Sterling and Kazamiari (1997) emphasized that in asphalt, where a binder can also act as an excellent lubricant, “We must have enough air voids to prevent the mix going plastic. We have to stay as far away from the Fuller curve as we realistically can”. According to Lees (1970), by considering the porosity of aggregate in a single size, and to minimize the same the two- component analysis of aggregate grading has been transformed in to multi component system. These factors elaborate the design considerations before choosing the aggregate blends of different sizes in the mix design. The aggregate gradation (Finn et al. 1976) has no significant influence on the elastic behavior of asphalt concrete. The effect of mixture gradation is confounded by the interrelationship (Haddock et al. 1999) between aggregate properties and volumetric as well as the selection of grading.

The design of asphalt mixture is largely a matter of selecting and proportioning constituent materials to obtain the desired properties in the finished pavement structures (The Asphalt Institute). However, when conventional mix design methods are fundamentally (www.asphaltexpertsystem.com/ index-files/LOGIC) experience- based, it is difficult to obtain desirable mix properties from these methods. It provides neither universal guidance nor safe procedures/physically validated criteria for the quality of bituminous mixes. The aggregate grading design and evaluation are part of this core issue for any bituminous mix.

About the Superpave gradations in USA, (http://www.nssga.org/pdf/whitepaper.pdf) the restricted zone in aggregate gradations is intended to eliminate poor performing humped grading that contains too much round natural sand in relation to total sand. Unfortunately, the restricted zone also eliminates many successful heavy duty, rut resistant mixtures produced with 100 % crushed aggregate from sources that have been used successfully for many years. Many States in the USA prohibit grading that pass through the restricted zone. At least ten states do not have a restricted zone requirement in their superpave specifications. States that have granite sources typically have very high-performance mixtures that pass through the restricted zone. Best economy is also achieved with these mixes due to the balanced aggregate skeleton that these blends create. Use of all particle sizes produced at an aggregate source is important for keeping extra production and inventory costs at a minimum.

Research currently being performed at National Centre for Asphalt Technology (NCAT) and elsewhere, suggests that asphalt mixtures made with aggregate gradings that pass through the restricted zone exhibit performance qualities equal to and even better than mixtures made with other grading of aggregate. The restricted zone is not needed, and its use in Superpave specifications should be eliminated. Differences often exist for certain geologic types of aggregates between the grading of aggregate used in laboratory design and the grading of the same aggregate products and proportions used in the field mixture. Consequently, aggregates obtained from the aggregate production plant may need to be 5 to 10% coarser (to account for grading changes that occur during transport, handling, and mixing) in order to meet mixture design volumetric requirements in the field. However, an aggregate product that is 5 to 10 % coarser at the aggregate production facility may not meet Superpave-grading requirements (and may be rejected from consideration).

Mixture designers, specifiers, and field plant personnel should become knowledgeable in the properties of aggregates obtained from specific sources, and should permit adjustment of aggregate grading during laboratory mixture design to be representative of the aggregate grading that will be received and used at the asphalt plant. South Carolina utilizes SA construction extensively throughout their Coastal Plain (Fletcher 1974). The performance of both surface and base SA on lightly and heavily traveled roads has generally been good. Their specifications limit the percent passing the No. 200 (0.074mm) sieve to 12%. The typical base course Marshall Stability requirement is 300lb (1.33kN) except for secondary roads for which there is no stability requirement.SA used in North Florida, the percentage passing No.200 sieve was restricted to 12%. These sands (West of Tallahassee) tend to be more angular and produce satisfactory stabilities. Sands with less than 12 % passing the No.200 (0.074mm) sieve and less than 7 % clay sized (0.005mm) have given good performance (Walker and Hicks 1976).

It was observed that the SA pavement sin Mississippi provided good service despite excessive VIM and that the poorest performing SA had mineral filler added to reduce the VIM. The majority of Mississippi's Coastal Plain is characterized by hilly areas of sandstone and shale as well as limestone. The central and northern portions of the state contain local deposits of well-graded alluvial sands, which typically produce 600 to 800 lb. (2.66 to 3.55kN)Marshall Stability SA mixes. When combined with stone screening of crushed gravel, these sands can form mixes with Marshall Stabilities well above 1000lb (4.44kN). As early as 1905, Richardson (1905) recognized the importance of performance of the relative proportions of the mixture components by volume in the bituminous mix. The grading of aggregates for bituminous mixes was generally considered for maximum density and minimum voids. This concept led to development of Fuller's curve (Fuller and Thompson 1907) and its modification by Brown et al. (1991). As per the findings by Furnace (1931) when two aggregates of different sizes were blended together, there was an optimum proportioning of the two components, which resulted in minimum voids, and this minimum void was always smaller than any of the voids in individual groupings of the aggregate. The character of the aggregate has far greater consequence in adhesion than the bituminous binder, which however exerted an appreciable influence.

3. METHODOLOGY

The methodology adopted in this research is systematic, comprehensive, and structured to ensure an accurate evaluation of Granulated Copper Slag (GCS) as an alternative aggregate for bituminous pavement construction. The overall process, illustrated in the flow chart in Figure 1, is divided into three major stages: material characterization, mix design trials, and optimization of mix properties. Each stage is designed to progressively assess the engineering, environmental, and performance-related suitability of GCS for use in Copper Slag Dust Base (CSDB) layers.

Stage 1 – Material Characterization

The first stage involves the detailed examination of GCS to understand its chemical, physical, and environmental characteristics. Chemical analysis is performed to determine the elemental composition of GCS, giving special attention to major constituents such as iron, silica, and alumina, as well as trace heavy metals. Environmental safety is addressed through the Toxicity Characteristic Leaching Procedure (TCLP), as prescribed by the U.S. Environmental Protection Agency (EPA, 2004). This test evaluates the potential of copper slag to leach hazardous substances, including heavy metals like lead, cadmium, arsenic, and chromium. The leachate concentrations obtained from the TCLP test are compared with regulatory limits defined by EPA and other governing bodies to confirm that GCS falls within permissible environmental thresholds.

Physical characterization of GCS includes determining properties essential for its application in bituminous works, such as particle size distribution, specific gravity, water absorption, angularity, and shape indices. Grading analysis is particularly critical because it helps determine the suitability of GCS for specific pavement layers. The gradation curve of GCS is compared with standard specifications, including ASTM D1073 and AASHTO M29, to identify whether GCS can be used directly or needs blending with finer materials. This detailed analysis ensures that the material meets the engineering requirements of bituminous mixes before moving to the design stage.

Stage 2 – Mix Design with GCS and Binder Variations

The second stage involves the preparation and testing of multiple CSDB mix combinations incorporating varying proportions of GCS, quarry dust (as a filler or fine fraction), and bituminous binder. GCS is treated as the coarser fraction in the mix, and quarry dust is incrementally added in proportions ranging from 20% to 80% to create a series of trial blends. These combinations correspond to Grading Index (GIc) values between 0.20 and 0.80, allowing the evaluation of gradation effects on mix performance.

Each mix is tested using the Marshall Compaction Method, employing 75 blows per side for compaction, and binder contents ranging from 4.5% to 6.0% by weight of aggregate. Marshall Stability, flow, density, air voids (VIM), voids in

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 11 | Nov - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

mineral aggregate (VMA), and voids filled with bitumen (VFB) are measured for each trial mix. These properties help in assessing structural stability, deformation resistance, and volumetric suitability of the GCS-based mixes.

Stage 3 – Optimization and Final Selection

In the final stage, results from all mix design trials are analyzed to identify the optimum proportion of GCS that satisfies design requirements without compromising pavement performance. The selection considers the balance between mechanical behavior, volumetric properties, environmental compliance, and material availability. This stage concludes with determining the ideal GCS–quarry dust blend capable of replacing conventional aggregates in bituminous base layers.

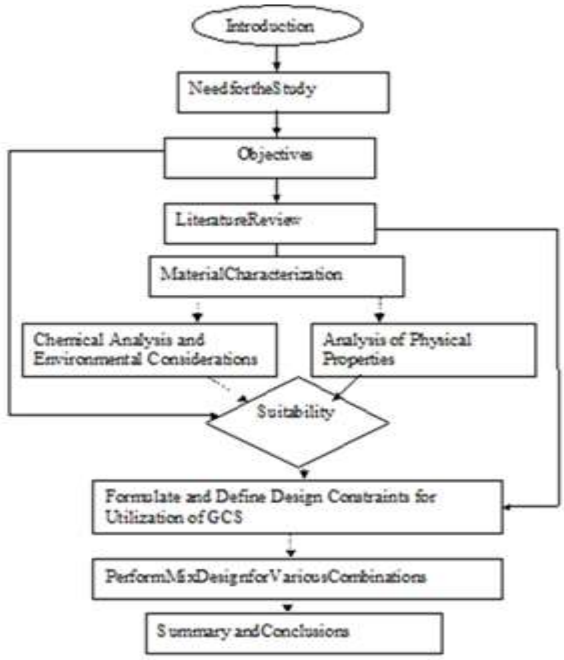

Figure 1. Flow Chart of Methodology

4. MATERIAL CHARACTERIZATION

Chemical Composition

The chemical analysis of GCS has been carried out to find the composition of elements. The chemical compositions along with their percentage concentration are given in Table 4.2. The materials like Iron and Silica are found to be at 43% and 34.90%, respectively. Materials like Sulfur, Zinc, Magnetite, Lime and Alumina are present in the range of 1-10%. The materials, which are present at less than 1%, are Cadmium, Magnesium, Arsenic, Cobalt, Molybdenum, Lead, Selenium, and Zinc along with Copper

Physical analysis

GCS has been analyzed for its physical characteristics. The grading analysis and other physical tests required for using it as an alternative aggregate have been conducted.

Table 2. Chemical Composition of GCS

SlNo.	Elements	Concentrationin%
1	Iron	43.0000
2	Silica	34.9000
3	Sulfur	10.0000
4	Zinc	4.3290
5	Alumina	3.1100
6	Lime	2.1100
7	Magnetite	1.0800
8	Copper	0.8000
9	Magnesium	0.2200
10	Molybdenum	0.0503
11	Arsenic	0.0236
12	Cobalt	0.0078
13	Lead	0.0038
14	Cadmium	0.0020
15	Selenium	0.0009
16	Others	0.3626
Total		100.0000

Grading of GCS

A grading analysis has been carried out for GCS samples. The results are given in Table 4.7.Maximum quantity of materials retained is found to be between 9.5 mm sieve to 600 mm sieve. The graduation requirements for fine aggregate as per standard specification for fine aggregate in bituminous paving mixtures ASTM D1073 (1996) and AASHTO M29 (1986) are given in Table 4.8 and Table 4.9 respectively. The gradations of GCS along with the three grading requirements of fine aggregate as per ASTM D 1073 are plotted in Figures 4.2 to 4.4. The percentage of passing in the sieve size 9.5mm, 4.75mm, 2.36mm, 1.18mm, and 600 micron are within the limits for grading1and3. In order to satisfy the above grading, the material finer than 300 microns has to be added. From Figure 4.3, it is ascertained that GCS cannot be used in bituminous mixes, which uses the ASTM grading 2, since the GCS grading is coarser than the limits prescribed in grading 2. Figure 4.5 shows the grading of GCS along with the limits in grading of fine aggregate asperAASHTOM29. It is observed that the material finer than 600 microns is required to be added with GCS in order to use the same with AASHTO M29 grading.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 11 | Nov - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Table3. Grading of GCS

Indian Standard Sieve size	Percentage Passed			
	Sample1	Sample2	Sample3	Average
9.5mm	100	100	100	100.0
4.75mm	98	97	94	96.3
2.36mm	79	80	74	77.7
1.18mm	64	72	68	68.0
600micron	26	35	28	29.7
300micron	5	6	4.5	5.2
150micron	1.5	1	1.5	1.3
75micron	1.1	1	1	1.0

Table 4.Comparison of Physical Characteristics of GCS with the Standard Specifications

S. No	Name of Test	Test Method	Test Values of GCS in %	MORTH (2001) Requirements in %	ASTMD692-96andASTM D1073 Requirements in %
1	Water Absorption	IS2386 PartI	0.232	Max2	--
2	Soundness Test with Sodium Sulfate	IS2386 PartV	1	Max12	Max15
	Soundness Test with Magnesium Sulfate		1	Max18	Max20
3	Los Angeles Abrasion Value	IS2386 Part IV	16	Max35	Max 40 for surface courses Max 50% for Base courses

5. DESIGN AND OPTIMIZATION

The mix design has been carried out in order to identify the suitable gradation, which accommodates more quantity of GCS as an aggregate in the CSDB mix. For this purpose, GCS is treated as a coarser part of the mix and found necessary to add finer particles in the mix, which has led to the application of fines smaller than GCS.

The quarry dust, which is finer than GCS, has been added incrementally to have different combinations. In order to maximize the quantity of GCS in the design, the mix trial started with proportioning of the material in such a way that GCS is kept at higher percentage of 80 and quarry dust is kept at 20 %. Then the quarry dust is added gradually and increased up to 80 % with an increase of 10 % for each mix.

This process leads to seven combinations of GCS and quarry dust. The proportioning determination has been carried out as per MS2 (2002) with Grading Index of GSB (GIc) starting from 0.2 to 0.8 and corresponding Grading Index of quarry dust (GId) at 0.8 to 0.2. The GIc values and their corresponding percentage passing are given in Table 5. The gradations of all these combinations are shown in Figure 5..

Table 5. Combined Aggregate Grading of CSDB Base

Sieve Size in mm	GIc						
	0.2	0.3	0.4	0.5	0.6	0.7	0.8
9.5	100	100	100	100	100	100	100
4.75	100	99	99	99	99	99	98
2.36	86	86	85	84	83	82	81
1.18	76	75	72	72	68	69	67
0.6	56	52	49	45	41	37	33
0.3	43	38	33	29	24	19	14
0.15	32	28	24	21	17	13	9
0.075	18	14	10	9	7	6	5

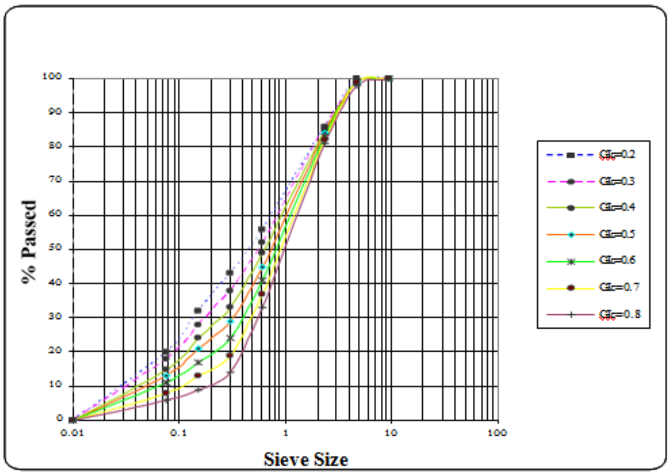

Figure 2. Grading of CSDB Trials

Mix Design by Standard Compaction

The Marshall moulds are prepared with 80/100 grade bitumen at 4.5%, 5%, 5.5%, and 6%of bitumen by weight of aggregate (Pba) by adopting Standard Marshall Compaction of 75 blows on each side of the mould. The prepared groups of moulds were tested in the Marshall testing machine as per the standard procedure in MS2(2002).The mix design performed on the above trials showed a significant improvement in the usage of GCS in bituminous mixes. The test values of mix properties like binder content by weight of mix (Pb), binder specific gravity (Gb), bulk specific gravity of mix (Gmb), D/A, VIM, VMA, Voids Filled with Bitumen (VFB), Stability (S),flow (f) and BFT are obtained for each GIc. The values of mix properties with Pba 4.5% are tabulated in Table 5.3.For other values of Pba 5%,5.5% and 6%, the mix properties are tabulated from Table 5.4 to Table 5.6, respectively.

Table 6. Mix Properties of CSDB Prepared with 4.5% Pba

Test Properties	GIc						
	0.8	0.7	0.6	0.5	0.4	0.3	0.2
Pbin%	4.31	4.31	4.31	4.31	4.31	4.31	4.31
Gb	1.012	1.012	1.012	1.012	1.012	1.012	1.012
Gmb	2.556	2.592	2.539	2.384	2.387	2.308	2.240
D/A	1.11	1.22	1.44	1.99	2.22	3.10	3.99
VIM	21.37	18.02	17.35	20.01	17.40	17.49	17.15
VMA	32.25	29.05	28.15	30.16	27.56	27.31	26.68
VFB	33.74	37.98	38.38	33.65	36.85	35.96	35.73
SinkN	1.56	5.28	5.62	6.84	8.45	5.17	4.45
Flow(f)inmm	2.15	2.13	2.50	2.05	2.15	2.20	2.35
BFTin microns	19.77	18.81	16.80	14.88	12.74	12.60	11.93

Aggregate Ratios

The CA and Fac ratio for all combinations of CSDB mixes starting from GIc of 0.2 to GIc of 0.8 were obtained as per the procedure laid down in TRCE (2002). The aggregate ratios CA and Fac for each GIc are shown in Table 7

Table 7. Aggregate Ratios of CSDB Mixes

GIc	Aggregate Ratio	
	CA Ratio	Fac Ratio
0.2	0.71	0.57
0.3	0.92	0.54
0.4	0.82	0.49
0.5	0.96	0.47
0.6	0.84	0.41
0.7	1.03	0.35
0.8	1.03	0.27

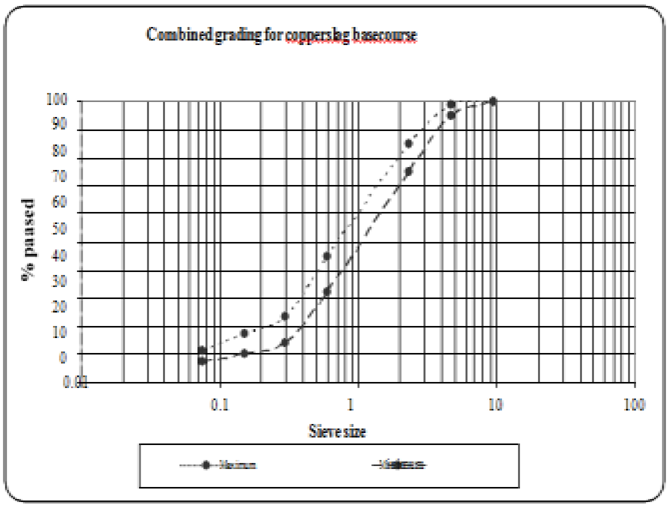

Figure 3. Grading Chart for CSDB

It is observed that the resource allocation can be effected by availability of resources. If the availability of aggregate dust is more, the mix representing GIc of 0.40 having 40% of GCS and 60% of aggregate dust can be used. On the other hand, if the availability of GCS is more, the mix representing GIc of 0.67 having 67% of GCS and 33% of aggregate dust can be used, without compromising any design values. The economical blend can also be obtained from the above optimization process, according to the cost of the resources.

SPECIFICATION FOR CSDB BASE

The specification for the CSDB shall be obtained by changing the design constraints as design requirements. The design requirements for CSDB mixes are shown in Table 8.

Table 8. Design Requirements for CSDB

S.No	Mix properties	Unit	Value
1	Stability	kN	Minimum5.00
2	VMA	%	Minimum20
3	VIM	%	15-20
4	D/A	--	Maximum2
5	BFT	Microns	Minimum10
6	CA	--	0.6-1.00
7	Fac.	--	0.35-0.50

Since these design requirements have been obtained from the optimization process with Pba range of 4.5% to 6%, the same range shall be adopted for Pba of CSDB base.

6. CONCLUSION

From the analysis of GCS for its usage as an aggregate in FABB, the following conclusions are arrived at:

Based on the TCLP test, the toxic element concentrations are within the regulatory limits given by EPA (2004). The physical properties conform to the ASTM and MORTH specification requirements for fine aggregates in bituminous works. GCS can be used as an alternative aggregate for bituminous works by considering the environmental and engineering properties. By optimizing GCS utilization in the mix without compromising the design requirements of specifications for FABB courses, CSDB yields desirable Marshall Properties and hence this can be used as a FABB course in the bituminous pavement construction. The designed grading of CSDB is capable of satisfying all the specifications from which the constraints are derived. Conventionally the design of bituminous mix is aimed at optimizing the Pba from the values of mixes obtained in a single aggregate grading selected from specification limits. By this method, the mixture composition may not be given as a single prescription. Instead, depending upon the availability of mixture constituents, the composition may be adjusted, without compromising any design requirements.

In this study, an attempt was made to optimize the usage of GCS as an aggregate in bituminous base. The studies include the literature review of bituminous mixes, their properties and specifications. The chemical and physical analyses have been carried out to find out the suitability of GCS in order to use the same in bituminous mixes. From chemical analysis, it has been observed that the toxic element concentrations are within the regulatory limits given by EPA. The physical properties conform to the ASTM and MORTH specification requirements for fine aggregates in bituminous works.

REFERENCES

1) AASHTO M29 (1986), 'Fine Aggregate for Bituminous Paving Mixtures', Standard Specification for Materials, American Association of State Highway and Transportation Officials, AASHTO Designation: M29-83, Part I Specifications, 14th Edition.

2) Anderson R., Michael and Hussain U. Bahia (1997), 'Evaluation and Selection of Aggregate Gradations for Asphalt Mixtures Using Superpave', Transportation Research Record 1583, Transportation Research Board, National Research Council, Washington, D.C.,pp. 91-97.

3) ASTM D692 (1996), 'Standard Specification for Course Aggregate for Bituminous Paving Mixtures', American Society for Testing and Materials, Designation: D692-94a, Annual Book of ASTM Standards, PART15.

4) Basel (2004), www.basel.int/convention.

5) Bhosale S.S., Mandal J.N. (2007), 'Cracking on Asphalt Concrete Overlays', Department of Civil Engineering, Research Report, IIT Bombay, Powai.

6) Brown S.F., Preston J.N. and Copper K.E. (1991), 'Application of New Concept in Asphalt mix design', Proceedings of AAPT, Vol. 60,p. 265.

7) Collins R.J. and Cielieski S.K. (1994), 'Recycling and Use of Waste Materials and By-Products in Highway Construction', National Cooperative Highway Program Synthesis of Highway Practice, Transportation Research Board, Washington, D.C.

8) FHWA (1998), 'Effects of Fine Aggregate Angularity on Asphalt Performance Mixtures', Report No. FHWA/IN/JTRP, Vol. 98, pp.130-136.

9) Finn F.N., Nair K. and Hilliard J. (1976), 'Minimizing Cracking of Asphalt Concrete Pavements', Proceedings of the Association of Asphalt Paving Technologists, Vol. 45, pp. 504-506.

10) Fletcher.O.S. (1974), 'The Use of Sand Asphalt Base in South Corolina', Asphalt Pavement Seminar, Mississippi State University.

11) Fuller W.B. and Thompsons E. (1907), 'The Laws of proportioning of concrete', Transactions of American Society of Civil Engineers Vol. 59, pp. 66-172.

12) Furnace C.C. (1931), 'Grading Aggregates, Mathematical Relations for beds of Broken Solids of Maximum Density', Industrial and Engineering Chemistry, Vol. 23, pp. 1052-1058.

13) Gallup G.H. (1974), 'White Pine Copper Company's Reverbaratory Furnace Slag for Highway Aggregates', Michigan Department of State Highways and Transportation Testing and Research Division, Lensing, p. 25.

14) Gibb J.M. and Brown S.F. (1994), 'A Repeated load Compression test for Assessing the Resistance of Bituminous mixes to Permanent Deformation', Proceeding of the Symposium University of Leeds, Department of Civil Engineering, University of Nottingham, UK,pp. 199-209.

15) Goode J.F. and Lufsey L.A. (1965), 'Voids, Permeability, Film Thickness vs. Asphalt Hardening', Proceedings of the AAPT, Vol. 34, pp. 430-463. Gorai B., Jana R.K. and Prem Chand (2003), 'Characteristics and Utilization of Copper Slag- A review', Resources, Conservation and Recycling, Vol. 39, pp. 299-313.

16) Hills J.F. (1973), 'The Creep of Asphalt Concrete Mixtures', Journal of the Institute of Petroleum.

17) HRBSR (1971), 'Bituminous Aggregate Base Course: Survey of State Practices', Highway Research Board, Special report 117.

18) Hubbard (1938), 'The Adhesion of Asphalt to Aggregate', Highways Research Board Proceedings 18, pp. 238.

19) Huddleson I.J., Zhou H. and Hikes R.G. (1993), 'Evaluation of Open Graded Asphalt Concrete Mixtures used in Oregon', Transportation Research Record No. 1427, pp. 5-12.

20) Hveem F.N. (1954), 'Gradation of Mineral Aggregates in Dense Graded Bituminous Mixtures', First Annual Bituminous Conference.

21) HWMHR (2004), 'Hazardous Waste (Management and Handling) Rules', Government of India, Schedule-4 [Rule 3(iii) & 19(i)] Notification, http://envfor.nic.in/.

22) IDOT (2006), 'Certified Hot Mix Asphalt Technical Manual' Chapter IV. Mix Characteristics and Behavior. Indiana Department of Transportation.

23) Indian Highways Editorial (2009), Indian Highways May 2009, Journal of Indian Road Congress, Vol. 37, No.5.

24) Kandhal P.S., Foo K.Y. and Mallick R.B. (1998), 'A Critical Review of VMA Requirements in Superpave', National Center for Asphalt Technology, Auburn, Alabama, NCAT Report No. 98-1.

25) Lees G. (1970), 'Rational Design of Aggregate Grading for Dense Asphalt Compositions', Proceedings AAPT, Vol. 39, pp. 60-90.

26) Lefebvre J. (1957), 'Recent Investigations of the Design of Asphalt PavingMixtures', Proceedings of the Association of Asphalt Paving Technologists, Vol. 26, pp. 435-442.

27) Mc Leod (1971), 'Designing Standard Asphalt Paving Mixtures for Greater Durability'. Proc. Canadian Technical Asphalt association, Vol. 16.

28) Mc Leod N.W. (1955), 'Discussion on J.H., Dillard's paper on Comparison of Marshall Specimens and Pavement Cores', Proceedings Of AAPT, Vol. 34, pp. 334-337.

29) Mc Leod N.W. (1956), 'Relationship between Density Bitumen Content and Voids Properties of Compacted Paving Mixtures', Proceedings of HRB, Vol. 35, pp. 432-437.

30) Mee E.C.E. (2006), 'The Effects of Nominal Maximum Aggregate Size on the Properties of Hot Mix Asphalt using Gyratory Compactor', Thesis Report University of Technology, Malaysia, November 2006.

31) NCAT (2002), 'Development of Mix Design Criteria for 4.75mm Super Pave Mixtures', Final Report, National Centre for Asphalt Technology.

32) NCHRP (2006), 'Volumetric Requirements for Superpave Mix Design' Transportation Research Record , Report 567. www.trb.org.

33) NCHRPR (1967), 'Factors Involved in the Design of Asphaltic Pavement Surfaces', National Cooperative Highway Research Program Report 39, Highways Research Board, pp. 79-83.

34) Organization for Economic Cooperation and Development (1977), 'Use of Waste Materials and Byproducts in Road Construction', OECD, Paris.

35) Performance of Coarse-Graded Mixes (PCGM 1998) at WesTrack - Premature Rutting. (Final Report). Federal Highway Administration. Washington, D.C. 1998.

36) Pine B. (2006), 'The Bailey method, Achieving Volumetric and Hot Mix Asphalt Compatibility', Course Note Pretoria, Heritage Research Group.

37) Rajiv K. Sinha and Sunil Hesat (2004), 'Health Impacts and Management Plans', pp. 121-122.

38) Shanmugsundaram V., Thirunakkarasu D. and Murugasan R. (2005), 'An Analysis of Causes of Premature Failure in National Highways of Tamil Nadu State in India', Indian Highways, September, Vol.33, No. 9, p.130.

39) Sinha S.N., Agarwal M.K. and Saha R.K. (1998), 'Pollution and its Control in Copper Industry', Journal of Environmental and Waste Management, pp. 185-196.

****