USE OF COPPER SLAG AS CONSTRUCTION MATERIAL IN BITUMENIOUS PAVEMENTS

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Abstract— Most of the pavements are made up of Hot mix asphalt as this is the most material available and it is also suitable for climate here. However hot mix asphalt pavements normally require frequent maintenance and rehabilitation due to damages caused by excessive traffic loadings. Therefore, one of the alternatives to minimize the damages of pavement and to prolong service life is use of modified asphalt pavements. The Stone matrix asphalt is a gap graded mix which is characterized by high coarse aggregates, high asphalt content and fiber additives as a stabilizer. Stone mix asphalt has proven very successful in Europe and American asphalt professionals are first to introduced the mix on a European asphalt study tour in 1990. In this present research an attempt has been made to study the volumetric properties of mixtures of Stone matrix asphalt and Hot mix asphalt. The research was done to check the fiber as stabilizing agent in a mixture by laboratory tests in which a flow parameter and stability were analyzed, further we did a research on using fiber size. For Hot mix asphalt we used gradation criteria given by NHA but gradation for Stone matrix asphalt we made a choice between three gradations by performing tests upon then and choosing the best one. Here we used grade 60/70 bitumen for both hot mix asphalt and stone matrix asphalt. Though enough research has been done in Pakistan but not being implemented so we have strong points in conclusion and recommendations of this report how it can be, and in which areas it can be useful for Pakistan and other countries.

Keywords— Copper Slag, Hot Mix Asphalt, Aggreagte, Bitumen, Optimum Bitumen Content

1 INTRODUCTION

Many countries are witnessing a rapid growth in the construction industry which involves the use of natural resources for the development of the infrastructure. This growth is jeopardized by the lack of natural resources that are available. The sustainable development for construction involves the use of non-conventional and innovative materials, and recycling of waste materials in order to compensate the lack of natural resources and to find alternative ways for conserving the environment. Aggregates are considered one of the main constituents of concrete.

Therefore, utilization of aggregates from industrial wastes can be alternative to the natural and artificial aggregates. In the last few decades there has been rapid increase in the waste materials and by-products production due to the exponential growth rate of population, development of industry and technology and the growth of consumerism. The basic strategies to decrease solid waste disposal problems have been focused at the reduction of waste production and recovery of usable materials from waste as raw materials as well as utilization of waste as raw materials whenever possible.

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Copper slag (CS) is one of the materials that is considered as a waste material which could have a promising future in construction industry as partial or full substitute of either cement or aggregates [1]. It is a by-product obtained during the smelting and refining of copper. Therefore, numerous contemporary researches have focused on the application of copper slag in bituminous mixes. The use of copper slag in bituminous mixes provides potential environmental as well as economic benefits for all related industries, particularly in areas where a considerable amount of copper slag is produced. The addition of copper slag as fine aggregate in various bituminous mixes improves interlocking and eventually improves the volumetric properties as well as the mechanical properties of the mixes. [2]

- Copper slag is a by-product of copper extraction by smelting. [3]
- Copper slag is a granular solid, ranges from 0.2mm to 3mm using as fine aggregates.
- A black viscous mixture of hydrocarbons obtained naturally or as a residue from petroleum distillation.
- Hot Mix Asphalt (HMA) is a combination of approximately 95% stone, sand, or gravel bound to-

gether by asphalt cement, a product of crude oil.

The objective of this research is to compare the properties of conventional HMA samples and HMA samples having some percentage of copper slag as a replacement of fine aggregates.

2 Literature Review

Asphalt pavement refers to any paved road surfaced with asphalt. Hot Mix Asphalt (HMA) is a combination of approximately 95% stone, sand, or gravel bound together by asphalt cement, a product of crude oil. Asphalt cement is heated aggregate, combined, and mixed with the aggregate at an HMA facility. The resulting Hot Mix Asphalt is loaded into trucks for transport to the paving site. The trucks dump the Hot Mix Asphalt into hoppers located at the front of paving machines. The asphalt is placed, and then compacted using a heavy roller, which is driven over the asphalt. Traffic is generally permitted on the pavement as soon as the pavement has cooled.

Hot mix asphalt paving mixtures may be produced from a wide range of aggregate combinations, each having its own particular characteristics suited to specific design and construction uses. In addition to the amount and grade of asphalt used, the principal characterizes of the mix are determined by the relative amounts of course aggregate, fine aggregate and mineral filler.

Pundhir et al (2005) studied that the copper slag (CS) was used as a fine aggregate (up to 40%). Marshall Method of mix Design is adopted in which CS as fine Aggregate. Addition of CS a fine aggregate in various bituminous mixes provides good interlocking and eventually improves volumetric and mechanical properties of bituminous mixes. Because of improved property by the incorporation of copper slag it can be used as a fine aggregate in bituminous mixes as the substitute of crusher dust as fine aggregate. [4]

Havanagi et al (2012) The waste like copper slag, zinc slag, steel slag was investigated for their suitability in road pavement, while copper slag and zinc slag may be used as a partial replacement of fine aggregate for the construction of sub base, base and bituminous layers. The specific gravity of copper slag, zinc slag and steel slag varied in the range of 2.75 – 3.6[5]

Kajal et al (2007) Study present the use of waste plastic and copper slag in hot bituminous mix to enhance pavement performance, bituminous mixes were prepared by mixing of graded mineral aggregate and increasing percentage of binder content 3.5%, 4%, 4.5%, 5%, 5.5%, by wt. of mineral aggregate. Optimum binder content is achieved by weight of mineral aggregate specimens are also prepared with composition of CS (10%, 20%, 30%and 40%). [6]

Debashish Kar et al (2014) Were Investigated the influence of cement as a filler in bituminous mixes, For comparison, control mixes with cement. Marshall test has been considered for the purpose of mix design as well as evaluation of paving mixes. Marshall stability and unit weight increase with bitumen content after which these two parameters decrease. At any bitumen content the stability value and unit weight are highest for mixes with cement as filler. Flow value increases with bitumen content. In the similar manner the air void decreases with increase in bitumen content. [7]

Mobasher et al. (1996) The slag contains some concentration of metals in the ores from which they were produced. Adding copper slag as a replacement of fine aggregates shown to have a significant influence on increasing the stability of bituminous mixes. [13]

From the above literature it is observed that copper slag has been used in construction of bituminous pavements. Copper slag has been suggested as a fine aggregate in limited quantities for bituminous mixes but not as an alternative to the aggregate in bituminous mixes.

The National Highway Authority (NHA) was created, in 1991, through an Act of the Parliament, for planning, development, operation, repair and maintenance of National Highways and Strategic Roads specially entrusted to NHA by the Federal Government. [14]

In this resreach we classified aggregates according to NHA Class A. It is important to know about pavement distresses before laying any pavement, as in which areas which type of distress can occur. There are various types of asphalt failures each with its own unique classification and repair approaches. Here we have explained some common pavement distresses and their remedies.

2.1 Rutting

Ruts in asphalt pavements are channelized depressions in the wheel-tracks. Rutting results from consolidation or lateral movement of any of the pavement layers or the subgrade under traffic. It is caused by insufficient pavement thickness; lack of compaction of the asphalt, stone base or soil; weak asphalt mixes; or moisture infiltration. [7]

2.2 Shoving

Shoving is the formation of ripples across a pavement. This characteristic shape is why this type of distress is sometimes called wash-boarding. Shoving occurs at locations having severe horizontal stresses, such as intersections. It is typically caused by: excess asphalt; too much fine aggregate; rounded aggregate; too soft asphalt; or a weak granular base.

2.3 Raveling

Raveling is the on-going separation of aggregate particles in a pavement from the surface downward or from the edges inward. Usually, the fine aggregate wears away first and then leaves little "pock marks" on the pavement surface. As the erosion continues, larger and larger particles are broken free and the pavement soon has the rough and jagged appearance typical of surface erosion. There are many reasons why raveling can occur, but one common cause is placing asphalt too late in the season. This is because the mixture usually lacks warm weather traffic which reduces pavement surface voids, further densification, and kneading of the asphalt mat. For this reason, raveling is more common in the more northern regions (Snow Belt). [7]

2.4 Bleeding

Bleeding is the accumulation of asphalt cement material at the pavement surface, beginning as individual drops which eventually coalesce into a shiny, sticky film. Bleeding is the result of a mix deficiency, asphalt cement content in excess of that which the air voids in the mix can accommodate at higher temperatures (when the asphalt cement expands). Bleeding occurs in hot weather but is not reversed in cold weather, so it results in an accumulation of excess asphalt cement on the pavement surface. Bleeding reduces surface friction and is therefore a potential safety hazard. [7]

2.5 Fatigue Cracking

Fatigue (also called alligator) cracking, which is caused by fatigue damage, is the principal structural distress which occurs in asphalt pavements with granular and weakly stabilized bases. Alligator cracking first appears as parallel longitudinal cracks in the wheel paths, and progresses into a network of interconnecting cracks resembling chicken wire or the skin of an alligator. Factors which influence the development of alligator cracking are the number and magnitude of applied loads, the structural design of the pavement (layer materials and thicknesses), the quality and uniformity of foundation support, the consistency of the asphalt cement, the asphalt content, the air voids and aggregate characteristics of the asphalt concrete mix, and the climate of the site (i.e., the seasonal range and distribution of temperatures). [9]

2.6 Thermal Cracking

Block cracking is the cracking of an asphalt pavement into rectangular pieces ranging from about 1 ft to 10 ft on a side. Block cracking occurs over large paved areas such as parking lots, as well as roadways, primarily in areas not subjected to traffic loads, but sometimes also in loaded areas
Block cracking and thermal cracking are both related to the use of asphalt cement which is or has become too stiff for the climate. Both types of cracking are caused by shrinkage of the asphalt concrete in response to low temperatures, and progress from the surface of the pavement downward. The key to minimizing block and thermal cracking is using an asphalt cement of sufficiently low stiffness (high penetration), which is nonetheless not overly temperature- susceptible (i.e., likely to become extremely stiff at low temperatures regardless of its penetration index at higher temperatures). [10]

2.7 Pathholes

A pothole is a bowl-shaped hole through one or more layers of the asphalt pavement structure, between about 6 inches and 3 feet in diameter. Potholes begin to form when fragments of asphalt concrete are displaced by traffic wheels, e.g., in alligator- cracked areas. Potholes grow in size and depth as water accumulates in the hole and penetrates into the base and subgrade, weakening support in the vicinity of the pothole. [11]

2.8 Stripping

Stripping is a loss of bond between aggregates and asphalt binder which typically progresses upward from the bottom of an asphalt concrete layer. It may be necessary to split the core apart to examine its interior. If stripping has occurred, partially coated or uncoated aggregates will be visible. Severe stripping represents a loss of structural integrity of the asphalt concrete layer, since its effective thickness is reduced as the stripping progresses. [12]

2.9 Slippage Cracking

Slippage cracking occurs as a result of a low-strength asphalt mix in the surface layer and/or poor bond between the surface layer and underlying layer, in areas where vehicles brake and turn. Slippage cracking is thus uncommon in highway pavements, but is common in local roads and streets, particularly at intersections. [8]

3 Research Mehodology

3.1 Lab Test

There are following test are performed

3.1.1 Aggregate Test

3.1.2 Bitumen test

3.1.3 Marshal test

` 3.1.1 Aggregate Test

This test involves the Follwing tests

3.1.1.1 Sieve Analysis

Standard reference used for this Test are AASHTO T27, ASTM C136. Sieve analysis also called Gradation. The particle size distribution, or gradation, of an aggregate is one of the most influential aggregate characteristics in determining how it will perform as a pavement material. Gradation helps determine almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage. Results are usually expressed in tabular format. The table is given below.

Sieve Size	Allowable % passing	% Passing taken
1''	100	-
¾''	90-100	94
½''	-	-
3/8''	56-70	58
#4	35-50	40
#8	23-35	25
#50	5-12	10
#200	2-8	5

3.1.1.2 Loss Abrasion Angeles

Standard reference used for this Test are AASHTO T96, ASTM C131. Aggregate undergo substantial wear and tear throughout their life. Test used to characterize toughness and abrasion resistance is the Los Angeles (L.A) abrasion test. For the L.A abrasion test, the portion of an aggregate sample retained on the 1.70mm (No. 12) sieve is placed in a large rotating drum that contains a shelf plate attached to the outer wall (the Los Angeles machine). A specified number of steel spheres are then placed in the machine, there is different grading of test means A, B, C, D and these classifications of grading have different number of spheres which were used. And the drum is rotated for 500 revolutions at a speed of 30– 33 revolutions per minute (RPM). The material is then extracted and separated into passing the1.70mm (No. 12) sieve. The retained material (larger particles) is then weighed and compared to the original sample weight. The difference in weight is reported as a percent of the original weight and called the percent loss.

Sieve (inch)	Retained On	Grading A
1-1/2	1	1250±10
1	¾	1250±10
¾	½	1250±10
½	3/8	1250±10

3.1.1.3 Impact value of aggregates

Standard reference used for this Test are BS 812 part III Aggregates are the combination of sand, sand, gravel, crushed stone or other material of mineral composition. Fine aggregates are defined as aggregates passing no. 4 (4.75mm) sieve and retained on no. 200(75 micron) sieve. Coarse aggregates are defined as aggregates retained on no.4 (4.75mm) sieve.

Test sample consist of aggregates passing 14mm and retained on 10mm sieve. Wash the sample and dry it at 100ºC to 110ºC for four hours and cool to room temperature. Fill the cylindrical measure with sample (M1) and tamp with 25 blows using tamping rod. Weight the sample. Take the sample to the machine cup. Raise the hammer and allow it to fall freely on the aggregates and compact it. The sample is subjected to the a total of 15 blows. Remove the sample and pass it through the sieve 2.36mm. The passing sample is weighed again (M2). And the retained sample on sieve is also weighed as (M3).

3.1.1.4 Specific Gravity & Water Absorption of Aggregates

Standard reference used for this Test are AASHTO T85, ASTM C127 for coarse and AASHTO T84, ASTM C128 for fine aggregates. Take a sample of 1000g and dry it at a temperature 110ºC. cool it in air temperature for 1 to 3 hours. Immerse the sample in water at room for 15 to 19 hours. Remove the sample from water and roll it in a large absorbent cloth until all visible films of water are removed. Take the mass of the sample in the saturated surface dry condition and use it as B in

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calculation. After taking the mass immediately place the saturated surface dry sample in the sample container and determine its mass in water at 23ºC and take it as C in calculations. Dry the sample at temperature of 110ºC. Cool it at room temperature for 1 to 3 hours and take the mass as A in calculations

3.1.2 Bitumen Lab Test

The following test are Performed

- 3.1.2.1 Penetration Grade of Bitumen
- 3.1.2.2 Softening Point of Bitumen
- 3.1.2.3 Flash and fire Point of Bitumen

3.1.2.1 Penetration Grade of Bitumen

It is the determination of Penetration Grade (Hardness) of bitumen, consistency. High penetration value -> softer consistency, preferred for colder climates. Refernces used for this test is AASHTO T49-97.

3.1.2.2 Softening point of bitumen

Softening point is the temperature at which substance attains a particular degree of softening under specified conditions. The determination of the softening point in the range from 30 to 157ºC using the ring ball apparatus immersed in the distilled water. Standard reference used for this Test are AASHTO T85, ASTM C127 for coarse and AASHTO T53-96.

3.1.2.3 Flash and fire Point of Bitumen

The temperature at which the vapors given off from the binder first burn with a brief flash of blue flame. The temperature at which vapours continue to burn for a period of at least 5 seconds. This test method is applicable to all petroleum products with flash points above 790C (1750F) and below 4000C (7520F) except fuel oils. Standard reference used for this Test are AASHTO T48-99, and AASHTO, ASTM D 92-96 for fine aggregates.

3.1.3 Marshal Test

By Marshall Test we can use the Stability and Flow values of the mix design samples. By this test we also determine the optimum bitumen content. And we also measure the strength and flexibility of asphalt mixtures. Standard reference used for this Test is ASTM 1559-76.

3.1.3.1 Sample preparation:

For obtaining the optimum moisture content for a particular gradation of aggregates by the Marshall method, a series of test samples are prepared for a range of different asphalt contents so that the test data curves show a well-defined “optimum” value. Tests should be scheduled on the basis of ½ percent increments of asphalt content, with at least two asphalt contents above “Optimum” and at least low below “optimum.” The bitumen content was added for HMA, they are 3.5%, 4%, 4.5%, 5%, 5.5% of each were prepared. And for CSMA bitumen content were added they are 10%, 20%, 30%,40%.

Figure: 3.1.3.1.1 Graded Sample

Figure: 3.1.3.1.2 Heating of Aggregates

Figure: 3.1.3.1.3 Sample in Mold

Figure: 3.1.3.1.4 Compacting Machine

Figure: 3.1.3.1.5 Sample Ejector

Figure: 3.1.3.1.6 Samples of Copper Slag Mix Asphalt

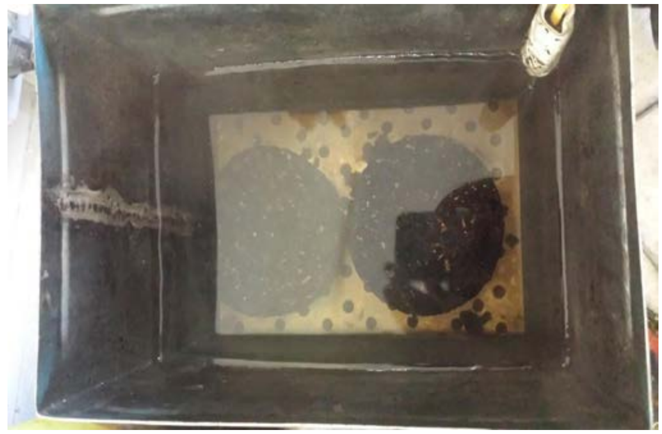


Figure: 3.1.3.1.7 Samples in Water bath

3.1.3.2 Test:

In this method each sample is subjected to the following tests

1. Stability and Flow
2. Density and voids analysis

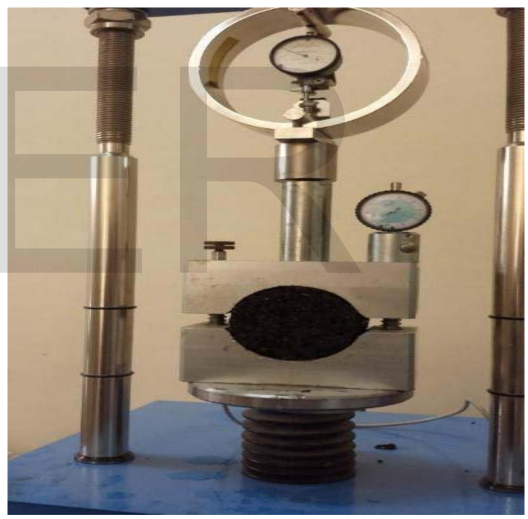


Figure: 3.1.3.2.1 Sample in Marshal Appartaus

4 RESULTS AND DISCUSSION

4.1 Aggregate Test

4.1.1 Los Angeles Test

Test	Value	Remarks

Los Angeles Test	23.47%	Allowed
Impact Value Test	14.56%	Strong
SG of Coarse Aggregates	2.48	Allowed
Water Absorption:	1.4%	Allowed

4.1.2 Bitumen Test

Test	value	Remarks
Penetration Grade of Bitumen	6.5mm	Used grading 60/70
Softening Point of Bitumen	36.25°C	Soft bitumen (35-43) ºC
Flash and fire Point	Flash point=326ºC Fire Point=332ºC	OK

4.1.3 Marshall Test

The following graphs shows the result of Marshall properties such as Marshall stability, Flow, Bulk specific gravity, Air voids, Voids in mineral aggregate and voids filled with bitumen.

4.1.3.1 Final Average Values (HMA):

Bitumen (%)	Stability (kg)	Flow (mm)	Air Voids	Unit Weight
3.5	495.9	8.9	7.6	2.31
4	625.9	9.9	5.76	2.34
4.5	542.19	10.9	3.372	2.38
5	411.14	12.4	2.963	2.377
5.5	385.05	13	3.06	2.375

Optimum Bitumen Content (OBC):
OBC = 4.26%

4.1.3.2 Final Average Values (10% Copper Slag):

Bitumen (%)	Stability (kg)	Flow (mm)	Air Voids	Unit Weight
3.5	748	8.8	6.32	2.398
4	799.39	9.3	5.55	2.399
4.5	856.50	10.1	4.52	2.406
5	822.4	11.7	3.90	2.412
5.5	812.18	12.2	3.25	2.409

Optimum Bitumen Content (OBC):
OBC = 4 . 8 0 %

4.1.3.3 Final Average Values (20% Copper Slag):

Bitumen (%)	Stability (kg)	Flow (mm)	Air Voids	Unit Weight
3.5	833.32	8.4	7.62	2.408
4	895.12	8.7	6.18	2.411
4.5	945.38	9.5	5.17	2.416
5	1032.52	10.4	4.50	2.418
5.5	908.73	10.8	3.86	2.413

Optimum Bitumen Content (OBC):
OBC = 5 . 1 3 %

4.1.3.4 Final Average Values (30% Copper Slag):

Bitumen (%)	Stability (kg)	Flow (mm)	Air Voids	Unit Weight
3.5	801.56	8.2	7.43	2.416
4	850.32	8.6	6.74	2.420
4.5	900.15	9.1	5.78	2.426
5	969.78	10	3.52	2.465
5.5	870.32	10.1	3.15	2.455

Optimum Bitumen Content (OBC):
OBC = 4.96%

4.1.3.5 Final Average Values (40% Copper Slag):

Bitumen (%)	Stability (kg)	Flow (mm)	Air Voids	Unit Weight
3.5	770.92	8	6.76	2.452
4	789.87	8.4	5.70	2.461
4.5	850.73	8.9	4.78	2.466
5	833.54	9.5	4.31	2.459
5.5	805.32	10	3.29	2.465

Optimum Bitumen Content (OBC):
OBC = 4 . 7 1 %

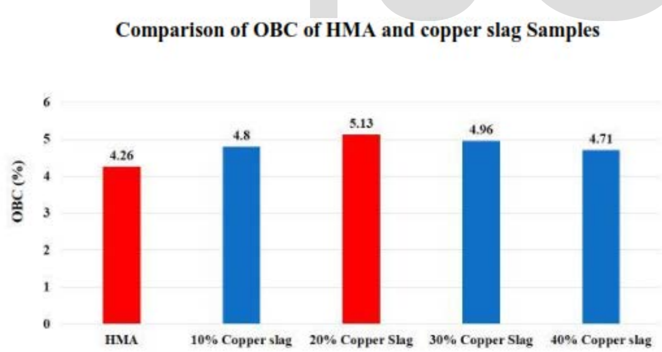
4.2 Comparison of Conventional HMA and HMA Having Different Percentages of Copper Slag:

Following are the main properties in comparison of conventional HMA and HMA Having Different Percentages of Copper Slag

Table 4.7

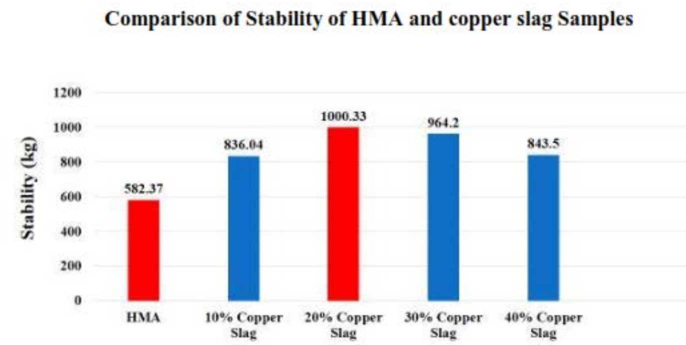
Mix	HMA	10% CS	20% CS	30% CS	40% CS
OBC (%)	4.26	4.80	5.13	4.96	4.71
Air Voids (%)	4.35	4.14	4.33	3.70	4.58
Flow (mm)	10.1	11.06	10.5	9.9	9.15
Unit Weight	2.355	2.409	2.416	2.461	2.463
Stability (kg)	582.37	836.04	1000.33	964.20	843.5
Gradation	NHA-A	NHA-A	NHA-A	NHA-A	NHA-A

Graph 4.2.1



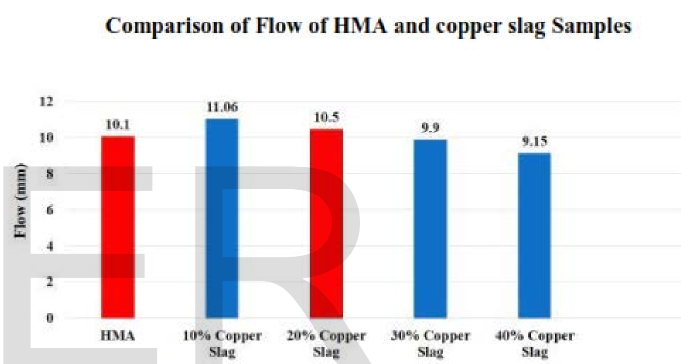
OBC comes out to be maximum at 20% CS than all other percentages of copper slag and conventional HMA.

Graph 4.2.2



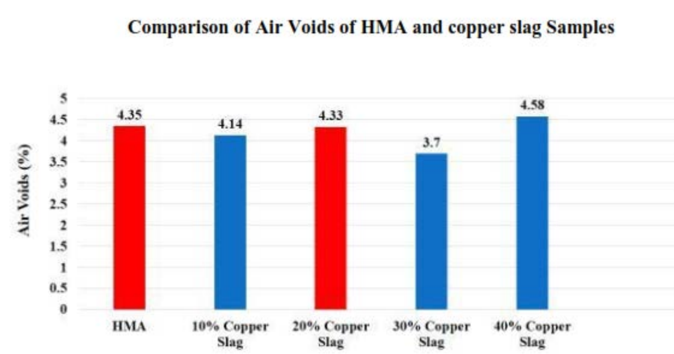
Value of stability at 20% copper slag is maximum as compare to all other percentages of copper slag and conventional HMA.

Graph 4.2.3



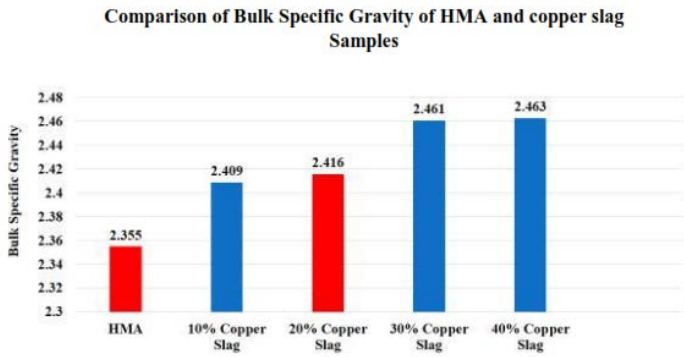
Flow value for 10% CS is higher than all other percentages of copper slag and conventional HMA.

Graph 4.2.4



Air voids remain almost same in all other percentages of copper slag and conventional HMA.

Graph 4.2.5



Bulk specific gravity increases as we increase the percentage of copper slag because of higher specific gravity of CS.

5. Conclusions and Recommendations

5.1 Conclusion: -

- Marshall Stability value for 20% copper slag addition is higher then 10%, 30% and 40% copper slag addition and almost double then conventional samples.
- The value of flow slightly changes up to 20% copper slag addition. It decreases after 20% copper slag up to 40%.
- Air voids remain almost same as compared to HMA at 20% copper slag.
- Air voids decreases at 30% copper slag and then again increases at 40% copper slag.
- Bulk specific Gravity slightly increases (almost 3%) at 20% copper slag. It continues to increase upto 40% copper slag, due to high specific gravity of copper slag.

5.2 Recommendation:

- By adding copper slag(20%) strength is maximum so it can be used in heavy traffic lane.
- Due to high strength of bituminous mix it can also be used in runways.
- A field study should be undertaken under different climatic conditions on National
  Highways of Pakistan.

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