Utilization of Copper slag as Fine aggregate in Bituminous Mix - a review

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Abstract

Industrialization of the world in 20th Century leads to production of huge industrial waste all over the world became a environmental issue. The recent researchers are focusing on the safe disposal of this solid waste. The use of solid waste from the copper industry called copper slag has the physical and mechanical properties resemble the fine aggregate utilized in the flexible pavement construction, hence it has the scope for the utilization of copper slag as fine aggregate partially or fully in the bituminous layer utilized in flexible pavement construction. Thereby the waste copper slag can be utilized as raw material for the road construction reduce the environmental issues and consumption of conventional fine aggregate obtained from the natural resources. This paper presents the comprehensive reviews on the possible use of copper slag as the substitute for conventional fine aggregate utilized in the pavement construction.

Key Words; Fine aggregate, copper slag, Pavement, Bituminous mix,

Introduction

In the mid of 19th century, the industry revolution has started results in developments of so many industry which produce so many useful products and industrial waste in the form of liquids and solids, they followed the concept linear economy "take, make, waste", is unsustainable. Leads to the accumulation of so many industrial waste such as slag, liquid waste, air pollutant, e-waste and fly ash etc., later it was realized that, this industrial waste are harming the earth by environmental impacts such as global warming, reduction on natural resources, negative effect on eco-system etc. In order to overcome this issue, the industry forced to shift from the linear economy to circular economy, which will focus on reduced use of natural non-renewable resources, reduce residue and increased use waste as raw materials to attain the vision of global sustainable goals as shown in Figure 1.

In research, the scientific methods are developed to dispose the liquid waste, but managing the solid waste such as copper slag, fly ash, red mud, silica fume and ground granulated blast furnace slag from the manufacturing industries are challenging, the only chance is to dispose in the land or reuse the solid waste from manufacturing industries. with they followed the concept "take, make, waste", is unsustainable. Leads to the accumulation of so many industrial waste such as copper slag, foundry slag, e-waste and fly ash etc.,

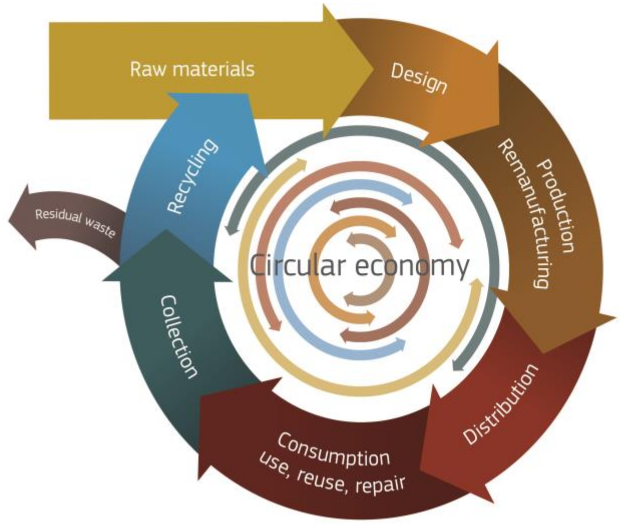

Figure 1 Circular Economy

Construction of road infrastructure consumes more quantity of natural resources such as river sand taken from river bed and broken stones taken from the rocks which affects the ecosystem and the biodiversity of the earth. In order to overcome this issue, wastes/by-products such as copper slag, fly ash, GGBS from industry should be used as raw material in the construction industry, especially in highway construction which consumes high volume of natural resource such as river sand and broken stones. The United States Environmental Protection Agency has listed the following advantage of using the industrial waste as raw materials are as follows,

- Natural resource can be preserved
- The energy spend on extracting the natural resource is reduced
- Green house gases get reduced

U.S. Environmental Protection Agency has also identified different ways of disposing the industrial wastes/by-products. Some of them are listed below.

a) Demolished concrete may be recycled (called as recycled aggregates) to be used as aggregates in the construction of highway pavements.
b) Crushed asphalt from the old highways may be used as coarse aggregates in pavements or structural fills.
c) Fly ash, furnace slag, and waste foundry sand may be used in embankments.
d) Coal ash may be used in cement and ceiling tiles manufacturing.
e) Flue gas desulfurization gypsum, waste foundry sand, and by-products from pulp and paper industries may be used in manufactured soil and agricultural amendments.

In the construction of road, the land acquired along the alignment is called right of way, It consists of following physical components such as side drain, shoulder, carriage way and embankment etc., Among which, the carriageway is the portion where the vehicle will pass was constructed either by flexible or rigid pavement. The pavement is a hard surface suitable for passing traffic in all season/weather laid over a road bed or sub grade which may be sand gravel, crushed rocks with binding material as bitumen, tar or cement as materials. The basic components of the pavement consist of sub grade, base course and wearing course (Hill Road Manual IRC SP48-1996) as shown in Figure 1. In the construction of flexible pavement, the wearing course and base course uses the dense bituminous mixes as shown in Figure 2.

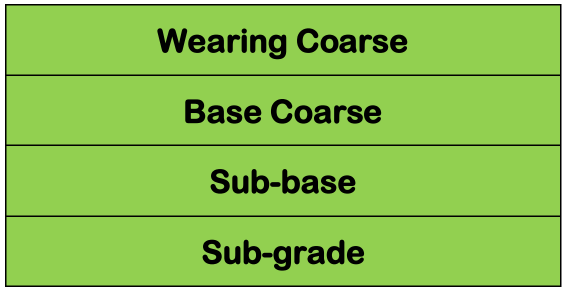

Figure 2 Structural Components of Flexible Pavement.

In Indian 90% of road is constructed by flexible pavement of total road network covers the total length of 54.83lakh kilometers (MoRTH, 2018). The pavement are subjected to the following structural failure due to traffic associated with loading and Environmental influences associated with temperature chances, storm water are such as depression, corrugation, potholes, shoving and rutting. The pavement failure such as bleeding, striping, raveling, polishing, roughness and patching etc., are categorizes as surface texture failure which means the pavement are structurally sound but the surface condition such as skid resistance, smooth running surfaces and water tightness etc., should get improved. **[1]** The bituminous surface course undergoes premature failure due to steep increase in traffic volume, movement of heavy vehicle, overloading causes various types of failure such as rutting, potholes, fatigue cracking etc., [2]**.** It has observed, that the life of asphalt layer of pavement was reduced considerably in the recent years **[3]**. It has observed that, the 80% of the asphalt pavement failure is contributed by the pavement distresses. Thus, the researchers have challenges to overcome or minimize this distress or bring down to zero distress in the new asphalt pavement construction, or rehabilitation of existing pavement. **[4].**In order to increase the asphalt mix properties such as fatigue life, aging, resistannce to rutting, and moisture resistance, the researchers modified the bitumen with polymers (elastomers and plastomers) such as chemical modifiers, crumb rubber, and natural rubber latex **[5].** The use of fibres started in the year 1950s. In bituminous overlay, they used wire mesh as reinforcement to arrest the reflective cracking [6]**.** It is found that, use of fibres improves the the strain energy absorbed when the asphalt mix subjected to the fatutge and fracture[7]. There was increased improvement in the tensile strength of the asphalt mix **[8].** The bituminous concrete incorporated with synthetic fibres are investigated throughout the world to by the researchers in order to improve the mechanical properties of the asphalt mix **[9, 10].** Hence, the researchers are focused on introducing innovation in the asphalt mix, which inherits the properties such as good interlocking between the aggregate, increased life of asphalt coating, resistance to distress, increase fatigue life and durability. Provided effective disposal of industrial waste contributing to the sustainable development of infrastructure facility provided the vehicle users get benefited by following factors such as reduction in travel time, maintenance cost, comfort and good riding quality.

Asphalt mix was the prime material in the construction of flexible pavement which consumes high volume of natural resources. Thus, asphalt mix has an important role to play in the future success of sustainable development. Asphalt mix considered as the right choice for achieving sustainable development due to following points. CO_2 emission – Use of recycled materials in manufacturing asphalt mix will reduce significantly the emission of greenhouse gasses, will prevent wastes being dumped as landfills, and also reduces consumption of raw materials. Recyclable – The pavement after completing its lifetime was demolished after they have served their intended purposes. The demolished pavement would generate huge quantities of waste materials consisting of broken crushed asphalt mix and aggregates with binder on their surfaces. These wastes may be collected and processes to attain shapes similar to conventional coarse aggregates used in pavement construction. After processing, they used as partial or complete replacement material for conventional virgin coarse aggregates being used for new pavement constructions. There is also scope for using them as backfills or as road base. Durability – Asphalt mix is durable for a period of 20 years. If a asphalt mix is degrading, it is primarily due to axle loading and environmental factors. Therefore, if degradation of flexible pavement prevented by proper means, the flexible pavement as such would sustain for longer period, and hence pavement structures may sustain natural disasters such as hurricanes, heavy rainfall, earthquakes and tsunamis.

Industrial Waste in Asphalt Mix

In the construction industries, the industrial wastes/by-products are being used as replacement materials for, fine aggregates or coarse aggregates at different percentages of replacement depending upon the required mechanical and volumetric properties of the sustainable asphalt mix. Some of the potential industrial wastes/by-products that may be used for flexible pavement construction process are fly ash, silica fume, copper slag, metakaolin, GGBS, red mud, waste foundry sand, coconut shells, and rice husk ash. Waste foundry sand is generated in huge volumes and are being dumped in to waste land because of space constraints in the industries which are actually generating them. With respect to manufacture of copper, report **[11]** says that production of one ton of copper generates approximately 2.2–3.0 tons of copper slag as a by-product. Report says India produces nearly 2.4 million tons of copper slag in the year 2015, which shared about 3.5% of world's total amount of copper slag generated. These lines give a clear understanding on the volume of industrial wastes/by-products being generated by the industries.

The following waste materials such as recycled materials, fly ash, ground granulated blast furnace slag, , slag from boilers, steel slag, and waste tires can be replace for the conventional materials in the construction of highway[12]. The use of waste materials should be encouraged in construction of highway after addressing the engineering, environment and economic concern before using in large scale[13]**.** The interlocking characteristics, volumetric and mechanical properties get improved up to 15% replacement of copper slag in dense bituminous mechadam. Studies indicate that there is large scope for using copper slag as replacement material for conventional fine aggregates used in concrete [14]. The stability get improved by 7% and the indirect tensile strength for temperature 25ºC, 35ºC, 45ºC, 55ºC and 60ºC has improved fatigue strength with partial replacement of copper slag than the conventional asphalt mix [15]**.** The following properties such as resilient modulus, tensile strength ratio, dynamic creep and fatigue resistance have better performance with 15% replacement of copperslag than the conventional asphalt mix [16].

The fifteen waste materials including the following industrial waste such as roofing shingle wastes, glass, fly ash and municipal solid waste combustion ash, rubber tires, carpet fibre, by-products of coal ash, blast furnace slag and steel slag, and recycled plastic are available in huge quantities from industry as wastes and by-products. The incorporation of the above wastes in highway construction in different structural components such as embankments, sub-grade, sub-base, base course, and wearing course reduce the use of depleting conventional natural resources and disposing constraints[17]. In global market, the Chile ranked number one in copper production with a share of 30% of total global copper production. The 80% of the economic activity depends on generation of copper raw material **[18].** Nearly 2.2 to 3.0 tons of copper slag are generated for every one tone production of copper leads to generate 4.5 million tons of copper slag every year, as of now totally 50 million tons copper slag get accumulated. Nearly 6, 00,000 MT of copper slag was produced every year in Tamil Nadu, India, Sterlite Industries. As a result, the researchers in need to scientific solution to safe disposal are reuse the quantity of copperslag gets accumulated as land fill. In chemical analysis it is found that, the copper slag has an following chemical composition such as iron oxide: 30 to 40%, silico oxide: 35 to 40%, aluminum oxide: 0 to 10% and calcium oxide: 0 to 10%. **[19].** In previous researches, it was found that the copper slag categorized under non-hazordous material **[20, 21].**

Several researchers investigated the feasibility of incorporating the copper slag obtained from the copper industry in the dense bituminous mixes as filler. The following mechanical properties such as stability, flow, indirect tensile strength, rutting resistance and fatigue life, volumetric properties such as air voids, voids filled with bitumen and voids in mineral aggregates. The research studies are reviewed in this section **t**he laboratory investigations on asphalt mix with partial replacement of reclaimed asphalt pavement varied as 50%, 60%, and 70% along with copper slag inclusion as 7.5% and 15% percentage to enhance the effectiveness of reclaimed asphalt pavement to design sustainable asphalt mixture. They found out that, the asphalt mix having 60% reclaimed asphalt pavement with 15% copper slag and 70% reclaimed asphalt pavement with 7.5 % copper slag showed better performance without compromising on following properties such as resistance to rutting, fatigue life, dynamic stiffness and moisture resistance[20]. The partial replacement of copper slag in dense bituminous macadam with varying percentage of 5%, 10%, 15%, 20% & 25% and found out that, the dense bituminous macadam 15% of copper salg replacing found to better perform without compromising the strength parameters such as tensile strength, fatigue resistance, resilient modulus and resistance to dynamic creep[21]. The performance of copper slag in the asphalt mix production and found out that, the copper slag contained asphalt mix uses low energy to raise the temperature of the material when compared to the convention asphalt mix. Hence it can be considered as siliceous aggregate due to improved thermal characteristics and also the mix containing the copper slag highly resistance to moisture and medium to long term aging[22].

Observations from the literature review

Through the industries, so many wastes such as steel slag, glass powder, copper slag, fly ash, ground granulated blast furnace slag, slag from boilers, steel slag, and waste tires etc., has being generated from industries all over the world. The researchers found out that, this waste can be utilized in different layers such as non bituminous layers such as sub-grade, granulated sub-base, wet mix mecadam and bituminous layer used such as dense bituminous concrete(DBM), bituminous concrete (BC) and seal coat etc.,

It was foundout that, the industrial waste copper slag obtained from copper industry has improved the mechanical properties such as fatigue life, indirect tensile strength, resistance to moisture sensitivity, rutting resistance, increased energy absorption capacity and increased stiffness was observed without compromising in volumetric properties required in asphalt mix. Hence the copper slag can be utilized as the replacing material for conventional natural aggregate utilized on the dense bituminous mixes thus we can reduce the depletion of natural resource, thus sustainable development of highway construction was achieved and the copper slag was safely disposed without harming the environment.

Conclusions

From the review of literature, it was observed that the industrial waste can be utilized in the road construction especially in the bituminous layer. The physical propertiies such as hardness varies from 6 to 7 with high specific gravity value of 3.4g/cc to 3.9g/cc. The volumetric properties such as air voids, voids filled with bitumen, voids in mineral aggregate of bituminous mix with copper slag was not affected when compared with the conventional bituminous mix. The mechanical properties such as stability, resistance to rutting, high abrasive resistance, fatigue life, high resistance to thermal stress and provided the durability also get increased hence utilization of copper slag in bituminous mix has future scope.

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