OPEN ACCESS INTERNATIONAL JOURNAL OF SCIENCE & ENGINEERING

COMPARATIVE ANALYSIS OF MODIFIED BITUMEN WITH BOTTOM ASH FOR INDIAN ROAD CONSTRUCTION

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Abstract: Importance in coal ash produced from thermal power plants as a substitute for conventional construction material has increased considerably in recent years. The utilization of coal ash not only solves a waste disposal problem but also provides an economic construction material. Very little has been developed on the productive use of both bottom ash and fly ash, primarily because of the lack of information on properties on this material. This work assesses those properties of bottom ash likely to affect its use in highway fill and pavement construction. Experimental investigations have been carried out for bottom ash which is collected from thermal plants. Physical properties such as appearance, grain size distribution and specific gravity of both ashes were also studied in various existing systems. The assessment of cost effective performance like cost evaluation for entire work. To evaluate potential highway construction uses, the test results were compared with those of representative granular materials and appropriate existing specifications. The study includes the replacement of bitumen with bottom ash at some percentages. The Proportion of the mix taken was of Bottom ash 8%, 10% and 12% and compared with cost effective scenario for conventional bitumen and bitumen with bottom ash road construction method.

I INTRODUCTION

Coal ash, a by-product of the thermal power plants, causes environmental pollution, but can also be used for gainful purposes. More than half of the electricity produced in the India is generated by coal-fired power plants by burning approximately 1,000 million tons of coal every year. In this process, 96 million tons of coal ash is produced. This coal ash consists of fly ash and bottom ash. Fly ash, being very fine, is carried through the furnace with the exhaust gases and is collected by ash precipitators. Bottom ash is heavier and falls through the bottom of the furnace, where it is collected in a hopper. Fly ash accounts for 70 to 80% of the coal ash, the rest being bottom ash. In the year 2020, approximately 19.6 million tons of bottom ash was produced. Of this total, 39% was gainfully utilized, the rest being disposed of in landfills or used to fill the mined out areas of coal mines prior to their reclamation. Disposal of coal ash is expensive and costs approximately $3/ton to $40/ton, depending on haul costs. In view of the high cost of disposal and environmental pollution caused by its generation and disposal, the gainful utilization of as much coal ash as possible is of vital importance. The utilization of coal ash as a raw material in applications that are environmentally and technically safe and commercially viable should lead to a reduction of the amount of these by products that end up in landfills. One such application of this bottom ash is as an aggregate replacement in pavement materials, as it possesses some of the properties similar to aggregate.

Road surface with cluttered bitumen may cause bleeding in hot weather and may develop cracks in cold weather possess fewer loads bearing capacity and can cause serious damages because of higher axial load in present conditions due to rapid infrastructure development. In the both terms length and quality, India has to raise its transportation system. Generally, production of asphalt comprises blending crushed rocks, fine aggregate with bitumen, which acts as a binding agent. Materials such as polymers could be added to alter its chemical and physical properties according to the use for which the asphalt is basically destined. Around the world, road authorities are realizing the use of modified bitumen is profitable in the road construction. Polymer modified bitumen is developed as one of the best construction material used for the flexible pavement. It reduces medium and long term cost as the roads are less exposed to defects. This reduces maintenance cost, which is not only a financial problem but also a traffic problem as road has to be closed for repairing or maintenance. Using waste bottom ash as enhancer in bituminous mix not only modify the properties of mix but also solve the problem of disposal of bottom ash and also creates employment to bottom ash collector.

Engineering properties of Coal ash

Figure 1 : Bottom ash

Generally, coal bottom ash has similarity with conventional aggregate used in construction industry. Physical and chemical properties influence coal bottom ash subsequent use and disposal. In environmental aspect, the treatment of coal bottom ash is subjected to regulations as a hazardous waste since it is not classified as general solid waste.

Figure 2 : Fly ash

II LITERATURE SURVEY

Bottom ash is listed as one of waste materials suitable for recycling in road construction [1] and by far is the most popular outlet for the material. Bottom ash is targeted to substitute sand or fine aggregates in road construction either as partially or full replacement due to its similar properties to natural sand. Coal Combustion Products Utilization Handbook [2], conducted a study on the performance of bottom ash in subgrade using plate load bearing tests. After one season, the road pavement was found to be in good condition indicating that the subgrade performed satisfactorily. In order to enhance the performance of the pavement, a recommendation has been made to use bottom ash in a 2 to 1 thickness ratio compared to normal base course material. [3] Summarized the uses of bottom ash as sub base, road-base materials and as bituminous mixes for binder layer. From the report, it is found that bottom ash provides adequate bearing capacity for lower strength application such as sub base materials and embankment fills [4]. On the other hand, the utilization of bottom ash in road base materials depends on the percentage content because the compressive strength is said to be reduced with an increase of bottom ash replacement percentage [5]. Besides that, low content of bottom ash in bituminous mixes is found practical as the ash not modify the mechanical characteristics of the mixture. Conversely higher content of bottom ash in the mix requires higher amount of bitumen in order to satisfy Marshall Mix design limit [6]. In addition, replacement material formulated with bottom ash and fly ash in subbase and road-base was found suitable for road embankment construction. The limitation is that low bottom ash to high fly ash ratio (ranging from 50 to 100% of fly ash content) was suggested for better performance and stability [7-8]. In four season country, a field study to identify the potential of bottom ash as insulation layer also has been conducted by [8]. The results indicate that bottom ash performed well as heat insulator and was effective in reducing frost penetration into the subgrade.

Recent studies in these directions have shown some hope in terms of using bottom ash-waste in road construction i.e. bottom ash roads. A Bangalore-based firm, KK Poly-flex and team of Engineers from R. V. College of Engineering, Bangalore, have developed a way of using bottom ash waste for road construction. The vigorous tests at the laboratory level proved that the bituminous concrete mixes prepared using the treated bitumen binder fulfilled all the specified Marshall mix design criteria for surface course of road pavement. There was a substantial increase in Marshall Stability value of bituminous concrete mixture, in the order of two to three times higher value in comparison with the untreated or ordinary bitumen. It had highlighted the developments in using bottom ash waste to make bottom ash roads in his research. Today, every vital sector of the economy starting from agriculture to packaging, automobile building construction, communication or InfoTech has been virtually revolutionized by the applications of bottom ash. Use of this non-biodegradable product is growing rapidly and the problem is what to do with bottom ash waste. If a ban is put on the use of bottom ash on emotional grounds, the real cost would be much higher, the inconvenience much more, the chances of damage or contamination much greater. The risks to the family health and safety would increase and above all the environmental burden would be manifold. Hence the question is not ‘Bottom ash Versus No Bottom ash’ but it is more concerned with the judicious use and re-use of bottom ash-waste.

The concept of utilization of waste bottom ash in construction of flexible road pavement has been done since 2000 in India. In the construction of flexible pavements, bitumen plays the role of binding the aggregate together by coating over the aggregate. It also helps to improve the strength and life of road pavement. But its resistance towards water is poor. A common method to improve the quality of bitumen is by modifying the rheological properties of bitumen by blending with synthetic polymers like bottom ash. Use of bottom ash waste in the bitumen is similar to polymer modified bitumen. The blending of recycled LDPE to asphalt mixtures required no modification to existing plant facilities or technology3 . Polymer modified bitumen has better resistance to temperature, water etc. This modified bitumen is one of the important construction materials for flexible Road pavement4 . Since 90's, considerable research has been carried out to determine the suitability of bottom ash waste modifier in construction of bituminous mixures.

Some worked on the rheological properties of bitumen modified by thermo bottom ash namely linear low density polyethylene [LLDPE], High density polyethylene (HDPE) and Polypropylene (PP) and its interaction with 80 penetration index bitumen. As it is known that the modification of bitumen by the use of polymers enhances its performance characteristics but at the same time significantly alter its rheological properties. The rheological study of polymer modified bitumen (PMB) was made through penetration, softening point and viscosity test. The results were then related to the changes in the rheological properties of PMB. It was observed that thermo-bottom ash copolymer shows profound effect on penetration rather than softening paint. The viscoelastic behaviour of PMB depend on the concentration of polymer, mixing temperature, mixing technique solvating power of base bitumen and molecular structure of polymer used. PP offer better blend in comparison to HDPE and LLDPE. The viscosity of base bitumen was also enhanced with the addition of polymer. The bottom ash behaviour was more prominent for HDPE and LLDPE than PP. Best results were obtained when polymer concentration was kept below 3%. Zoorab and Suparma8 reported the use of recycled bottom ash composed predominantly of polypropylene and low density polyethylene in plain bituminous concrete mixtures with increased durability and improved fatigue life. Dense bituminous macadam with recycled bottom ash, mainly low density polyethylene (LDPE) replacing 30% of 2.36-5 mm aggregates, reduced the mix density by 16% and showed a 250% increase in Marshall Stability. The indirect tensile strength (ITS) was also improved in the mixtures. D. N. Little, works on the same theme and he found that resistant to deformation of ash, concrete modified with low density polyethylene was improved in comparison with unmodified mixtures. It is found that the recycled polyethylene bags may use full in bitumen pavement resulting in reduced permanent deformation in the form of rutting and reduced low temperature cracking of pavements surfacing.

Bindu and Beena investigate the benefits of stabilizing the stone mastic asphalt (SMA) mixture in flexible pavement with shredded waste bottom ash. Conventional (without bottom ash) and the stabilized SMA mixtures were subjected to performance tests including Marshall Stability, tensile strength and compressive strength tests Trim axial tests were also conducted with varying percentage bitumen by weight of mineral aggregate (6% to 8%) and by varying percentage bottom ash by weight of mix (6% to 12% with an increment of 1%). Bottom ash content of 10% by weight of bitumen is recommended for the improvement of the performance of Stone Mastic Asphalt mixtures. 10% bottom ash content gives an increase in the stability, split tensile strength and compressive strength of about 64%, 18% and 75%, respectively compared to the conventional SMA Mix. Taxied test results show a 44% increase in cohesion and 3% decrease in angle of shearing resistance. Showing an increase in the shear strength. The dram down value decreases with an increase in bottom ash content and the value is only 0.09 % at 10% bottom ash content and proves to be an effective stabilizing additive in SMA mixtures11. Stone Mastic Asphalt is a gap graded bituminous mixture containing a high proportion of coarse aggregate and filler, it has low air voids with high levels of macro texture when laid, resulting in a waterproof layer with good surface drainage. Stabilizing additives are needed in the mastic which is rich in binder content to prevent the binder from draining down from the mix. Polymers and fibres are the commonly used stabilizing additives in SMA. Based on many research reports and engineering case studies has been shown that the use of stone mastic asphalt (SMA) on road surfaces can achieve better rut-resistance and durability.

III RESEARCH METHODOLOGY

Materials required for construction of surface course in flexible pavement are as follows:

- Aggregates
- Bottom ash as modifier
- Bitumen Aggregates

Aggregates are the materials which are used in surface course and can be divided into two types according to their size: coarse aggregates and fine aggregates. Coarse aggregates are generally defined as those aggregates which are retained on the sieve size of 2.36 mm. Whereas Fine aggregates are those that pass through sieve size of 2.36 mm and are retained on the 0.075 mm sieve. Aggregates which are required for the research work can be obtained from the local market. Bottom ash Waste as modifier Modifiers or additives are hereby used to reduce the air void present between aggregates which will enhance the properties of bituminous concrete mixes and also modifiers bind the aggregates together so that no bleeding of bitumen will occur. For the present study, bottom ash waste such as carry bags, water bottles, milk packets, glasses, cups, etc, will be used as a modifier.

Material Selection

Bottom Ash (BA) used in this research was obtained from a coal-fired thermal power plant sited in Nashik (MH). The bitumen was obtained locally and the BA and bitumen were dried at 170˚C for 24h and sieved. In order to achieve the objectives of the study, a thorough review is done to have knowledge of the works available in literature. First of all collection of bottom ash waste can be done. After that shredding or cutting of bottom ash into small pieces can be done. After that ordinary tests can be performed on aggregate and bitumen. After that using bottom ash waste coating of aggregate can be done and tests will performed. After that bottom ash is mixed with bitumen and laboratory tests can be performed. At last comparison of both test results with and without bottom ash waste can be done.

1. Selection of Materials.

2. Basic Tests performed on bitumen and aggregate.

3. Prepare DBM mix design.

4. Prepare conventional bitumen sample.

5. Testing of conventional concrete specimen.

6. Result of conventional bitumen.

7. Preparation of modified bitumen using 8%, 10%, 12% with bottom ash.

8. These modified bituminous mix moulds are tested by conducting Marshall Stability

9. Result for modified bituminous mix.

10. Comparison between conventional bitumen and modified bitumen

Waste bottom ash is ground and made into powder; As per IRC 098:2013, waste bottom ash mixed with the bitumen is 8% , 10% and 12% of weight of bitumen. Use shredded bottom ash waste acts as a strong bitumen agent for tar making the asphalt last long. About 30% of bottom ash is re-purposed and recycled in a variety of ways. Most recycled bottom ash is used for snow and ice control, as a road base, structural fill material, or a raw feed material for some cements.[1] Bottom ash can also be added into hot asphalt, however, it is a fairly fine powder and has a low durability. Because of this there is usually a sifting process to collect the larger particles when used in asphalt.

Bottom ash that is not to be recycled is discarded in landfills or storage lagoons. If the bottom ash goes to a storage lagoon, it is generally mixed with fly ash and referred to collectively as ponded ash. About 30% of all coal ash is disposed of when wet as ponded ash.[1] This ash is potentially usable even after it is put in a storage lagoon. Because fly ash and bottom ash have different weights, the heavier bottom ash settles first and the fly ash remains suspended. This ponded ash can be reclaimed if the bottom ash is scraped up and dewatered.[1] The more bottom ash that is in ponded ash, the easier it is to dewater and the more potential it has for reuse. This reclaimed ash can be used in embankment construction or as a filler. Another important observation was that the bituminous mixes prepared using treated binder could withstand adverse soaking conditions under water for longer duration. In the first we need to do some basic process on our selected material e.g., waste bottom ash contains some unnecessary substances so, we must need to follow basic procedure before field trails which is mention in below

Segregation

Bottom ash is part of the non-combustible residue of combustion in a power plant, boiler, furnace or incinerator. In an industrial context, it has traditionally referred to coal combustion and comprises traces of combustibles embedded in forming clinkers and sticking to hot side walls of a coal-burning furnace during its operation. The portion of the ash that escapes up the chimney or stack is, however, referred to as fly ash. The clinkers fall by themselves into the bottom hopper of a coal-burning furnace and are cooled. The above portion of the ash is also referred to as bottom ash. Bottom ash is the coarse, granular, incombustible by-product of coal combustion that is collected from the bottom of furnaces. Most bottom ash is produced at coal-fired power plants. Bottom ash can is extracted, cooled and conveyed using dry ash handling technology. When left dry the ash can is used to make concrete, bricks and other useful materials. There are also several environmental benefits. Bottom ash may be used as raw alternative material, replacing earth or sand or aggregates, for example in road construction and in cement kilns (clinker production). A noticeable other use is as growing medium in horticulture (usually after sieving). It is known as furnace bottom ash (FBA), to distinguish it from incinerator bottom ash (IBA), the non-combustible elements remaining after incineration.

- Bottom ash waste collected from thermal power plant.
- Maximum thickness of 60 microns

Figure 3 : Bottom ash

Mix Design

The BA was used to replace the bitumen in the mixture; thus the BA was sieved out and smaller than sieve No. 4 (4.75 mm) was used in this study. The aggregate was tested according to gradation of the aggregate used in the mixture. The asphalt mixture contains the BA with percentages of 0 % (control mix), 8 %, 10 % and 12 % by the total of bitumen in weight. The virgin and ash aggregates were fractioned into individual sieve sizes to provide the requirement of fine aggregate, and then recombined again to meet the requirement of gradation. Table 6.3 presents the detailed information how each fraction of fine aggregate was replaced with the BA. Since the gradation of BA has the same gradation as the virgin aggregate to be replaced, the gradations of total aggregate for all HMA specimens are same.

Due to the limited amount of BA, the researchers decided to make smaller specimens; thus the Marshall Mix design was used for the sample preparation. For each proportioning, three specimens were prepared for performance tests, and the average value of three specimens is reported in later sections. The mixtures with 8, 10, and 12% of replacement by the BA were prepared with this percentage of bitumen.

For the flexible pavement, hot stone aggregate (170°C) is mixed with hot bitumen (160°C) and the mix is used for road laying. The aggregate is chosen on the basis of its strength, porosity and moisture absorption capacity as per IS coding. The bitumen is chosen on the basis of its binding property, penetration value and viscous-elastic property. The aggregate, when coated with bottom ashs improved its quality with respect to voids, moisture absorption and oundness. In this process the shredded bottom ashs are poured over the heated aggregates, thus forming bottom ash coated aggregates which are then mixed with hot bitumen to form bottom ash coated aggregate bitumen mixture for laying roads. The coating of bottom ash decreases the porosity and helps to improve the quality of the aggregate and its performance in the flexible pavement.

Figure 4: The aggregate is heated to 170°C in the Mini hot Mix Plant

Then the shredded bottom ash waste is added in equal proportion.

Figure 5 : Adding BA into bitumen

Immediately the hot Bitumen 60/70 or 80/100 grade (160°C) is added .

Figure 6 : Aggregate-BA- Bitumen Mix

Finally the mixture is transferred to the road and the road is laid.

Bottom ash produced as a waste product can be a good construction material for roads and embankments. The benefits obtained due to use of Bottom ash as embankment fill material are well known. Adoption of ash in embankment construction will result in saving of precious topsoil besides leading to reduction in construction cost. At a time, when infrastructure development is getting top priority and construction of many road projects are being planned, greatly enhanced demand can be expected from the road sector. Unfamiliarity with the use of Bottom ash in road works can be overcome through demonstration projects and educating the construction agencies. But adequate attention should be paid to characterisation of Bottom ash and quality control during construction for better performance so that fly ash can be turned from a liability to an asset converting ash to cash.

IV RESULTS AND DISCUSSIONS

Table 1 : Physical properties of bottom ash

Sr. No.	Test Particular	Unit	Test Result	Test Method
1	Specific gravity	-	2.26	IS 3812 Part-I
2	Material retain on 45 Micron (Wet Sieving)	%	13.23	

1 Conventional Approach no replacement of bottom ash

Table 2 : Conventional Approach no replacement of bottom ash

Sr. No.	Ingredients	Dry Mix formula (in percentage)
1	20 mm coarse aggregate	34
2	10 mm coarse aggregate	14
3	6 mm coarse aggregate	6
4	Crushed sand fine aggregate	44
5	Filler (stoned dust)	2
6	Bitumen (VG-30)	4.5%

2 Bottom ash replacement with 8%

Table 3 : Bottom ash replacement with 8%

Sr. No.	Ingredients	Dry Mix formula
1	20 mm coarse aggregate	34
2	10 mm coarse aggregate	14
3	6 mm coarse aggregate	6
4	Crushed sand fine aggregate	44
5	Filler (stoned dust)	2
6	Bitumen (VG-30)	5%
7	Bottom ash	8%

3 Bottom ash replacement with 10%

Table 4 : Bottom ash replacement with 10%

Sr. No.	Ingredients	Dry Mix formula
1	20 mm coarse aggregate	34
2	10 mm coarse aggregate	14
3	6 mm coarse aggregate	6
4	Crushed sand fine aggregate	44
5	Filler (stoned dust)	2
6	Bitumen (VG-30)	4.8%
7	Bottom ash	10%

4 Bottom ash replacement with 12%

Table 5 : Bottom ash replacement with 12%

Sr. No.	Ingredients	Dry Mix formula
1	20 mm coarse aggregate	34
2	10 mm coarse aggregate	14
3	6 mm coarse aggregate	6
4	Crushed sand fine aggregate	44
5	Filler (stoned dust)	2
6	Bitumen (VG-30)	4.5%
7	Bottom ash	10%

5 Cost Calculation

Cost of Bottom ash

- The basic Cost of Bottom ash is around: **Rs. 0.50 / Kg. (Source :** https://www.indiamart.com/proddetail/bottom-ash-14540771997.html#:~:text=Bottom%20Ash%2C%20Grade%3A%20Astm%2C,ton%20Phenix%20Enterprise%20%7C%20ID%3A%2014540771997 **)**
- Other Cost: **Rs. 0.10 / Kg.**
- Total cost Bottom ash: **Rs.0.60 / Kg.**

Cost of Bitumen

- The Cost of Bitumen: **Rs.8400 / Drum (200 Kg.)[6]**
- The Cost of Bitumen: **Rs.42 / Kg. (as per IS standard)**

1. Actual amount or cost of road by conventional method having 500 meter length and 4 m. width as per SSR Cost – 12,83,120 INR

- Bitumen content in Bituminous Concrete (BC) is 4.5% of weight
- Total BC required for road of 500 m length, 4m width, and 1mm thickness 60 m3
- Total bitumen content in 60 m3
  60 m3 * 2.41 = **144 tonne**
  144 tonne *1000= **1,44,600 Kg.**
  Bitumen required (4.5%) **= 6507 Kg. (total bitumen required)**
  Cost of bitumen **: 6507*42 = 2,73,294 INR**

= 2,73,294 Rs. bitumen required for this road using conventional approach

Replace bitumen with plastic 8%, 10% as well as 12% respectively

Bitumen required (5%) **= 7230 Kg. (total bitumen required)**

8% bottom ash of 7230 Kg. bitumen = 579 Kg.

579*0.60 = 348 (bottom ash cost)
579*42 = 24318 (actual bitumen cost)
Total save = 24318-348
= 23,970
Bitumen required (4.8%) **= 6941 Kg. (total bitumen required)**

10% bottom ash of 6941 Kg. bitumen = 694 Kg.

694*0.60 = 416 (bottom ash cost)
694*42 = 29148 (actual bitumen cost)
Total save = 29148-416
= 28,732
Bitumen required (4.5%) **= 6507 Kg. (total bitumen required)**

12% bottom ash of 6507 Kg. bitumen = 781 Kg.

781*0.60 = 469 (bottom ash cost)
781*42 = 32802 (actual bitumen cost)
Total save = 32802-469
= 32,333

6 Observation

6.1 Marshall stability Test

Table 6 : Marshall stability tests

Sr. No.	Bitumen	Bottom ash (replace to bitumen)	Unit	Average Marshall stability at 60C.
1	4.5	Nil	kN	10.53
2	5.0	8%	kN	10.91
3	4.8	10%	kN	11.25
4	4.5	12%	kN	**11.57**

6.2 Cost analysis

Table 7 : Cost calculation with 8%, 10% and 12% bitumen replacement with BA

Road type	Actual bitumen cost	Replace bitumen with 8% BA	Actual bitumen cost	Replace bitumen with 10% BA	Actual bitumen cost	Replace bitumen with 12% BA
500 m road	24,318	348	28,732	416	32,802	469

Table 8 : Cost difference with 8%, 10% and 12% bitumen replacement with BA

Road type	Only bitumen	Replace 8% BA cost reduction over bitumen	Replace 10% BA cost reduction over bitumen	Replace 12% BA cost reduction over bitumen
500 m Road	Nil	23,970	28,732	32,333

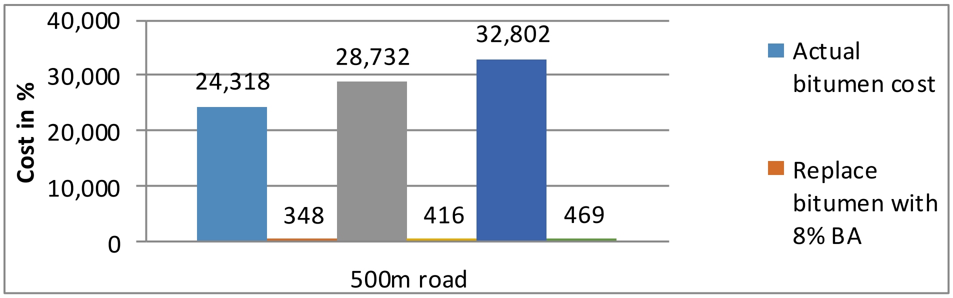

Figure 7: bitumen and BA cost

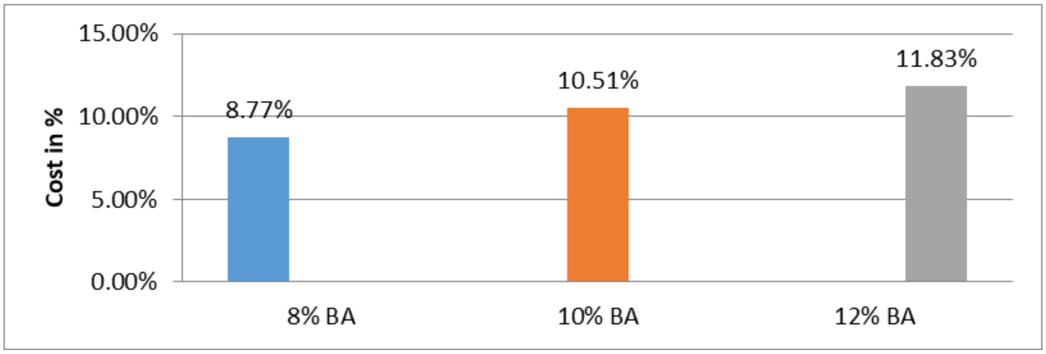

Figure 8 : Cost reduction after replacement of bitumen over BA

V CONCLUSION

Bitumen Ash (BA) will increase the melting point of the bitumen and use of the innovative technology not only strengthened the road construction but also increased the road life. It also help to improve the environment and BA road would be a boon for India's hot and extremely humid climate where durable and eco-friendly roads which will relive the earth from all type of BA . Polymer Modified Bitumen is used due to its better performance. But in the case of higher percentage of polymer bitumen blend, the blend is a more polymer dispersion in bitumen, which get separated on cooling. This may affect the properties and quality of the blend and also the road laid using such blend.

(i)We have three different Marshall Test to replace bitumen with BA (8%, 10% and 12%) including conventional bitumen.

(ii)The 12% replacement of bitumen with BA provides optimum results for stability as well as cost.

(iii)The 12% replacement of bitumen provides highest 11.57 stability, it is higher than 10% and 8% replacement of bitumen with BA.

(iv)Similarly the 12% replacement of bitumen reduce the cost with 11.83, it is higher than 10% and 8% replacement of bitumen with BA.

(v)Blending requires a special type of mixing assembly for proper and effective blending.

(vi)Increase and decrease in specific values of bitumen shows improved performance of bitumen which in turn helps to improve quality and durability of road.

(vii)When modified bitumen is to be used at site of construction; there should be provision of maintaining proper service temperature and blending to prevent phase separation.

In the modified process (dry process) BA is coated over aggregate. This helps to have better binding of bitumen with the BA coated aggregate due to increased bonding and increased area of contact between polymer and bitumen. The polymer coating also reduces the voids. This prevents the moisture absorption and oxidation of bitumen by entrapped air. This has resulted in reduced rutting, ravelling, and there is not pothole formation. The road can withstand heavy traffic and show better durability.

REFERENCES

[1] Lynn CJ, Ghataora GS, OBE RKD. 2017 Municipal incinerated bottom ash (MIBA) characteristics and potential for use in road pavements. International Journal of Pavement Research and Technology. 10(2):185-201.

[2] Jayaranjan MLD, Van Hullebusch ED, Annachhatre AP. 2014 Reuse options for coal fired power plant bottom ash and fly ash. Reviews in Environmental Science and Bio/Technology. 13(4):467-86.

[3] Coal Combustion Products Utilization Handbook. 3rd ed: We Energies Publication; 2013. 448 p.

[4] Poulikakos L, Papadaskalopoulou C, Hofko B, Gschösser F, Falchetto AC, Bueno M, et al. 2017 Harvesting the

unexplored potential of European waste materials for road construction. Resources, Conservation and Recycling. 116:32-44.

[5] Colonna P, Berloco N, Ranieri V, Shuler S. 2012 Application of bottom ash for pavement binder course. Procedia-Social and Behavioral Sciences. 53:961-71.

[6] Kim B. Properties of coal ash mixtures and their use in highway embankments. 2003. [23] Kim B, Prezzi M, Salgado R. 2005 Geotechnical properties of fly and bottom ash mixtures for use in highway embankments. J Geotech Geoenviron Eng. 131(7):914-24.

[7] Haghi NT, Nassiri S, Shafiee MH, Bayat A. 2014 Using field data to evaluate bottom ash as pavement insulation layer. Transportation Research Record. 2433(1):39-47.

[8] Sadon SN, Beddu S, Naganathan S, Kamal NLM, Hassan H. 2017 Coal Bottom Ash as Sustainable Material in Concrete–A Review. Indian Journal of Science and Technology. 10(36)

[9] Singh M, Siddique R. 2013 Effect of coal bottom ash as partial replacement of sand on properties of concrete. Resources, conservation and recycling. 72:20-32.

[10] Kim H-K, Lee H-K. 2011 Use of power plant bottom ash as fine and coarse aggregates in highstrength concrete. Construction and Building Materials. 25(2):1115-22.

[11] Mandal A, Sinha O. 2014 Review on current research status on bottom ash: An Indian prospective. Journal of The Institution of Engineers (India): Series A. 95(4):277-97.

[12] Singh M, Siddique R. 2014 Strength properties and micro-structural properties of concrete containing coal bottom ash as partial replacement of fine aggregate. Construction and Building Materials. 50:246-56.

[13] Aggarwal P, Aggarwal Y, Gupta S. 20017 Effect of bottom ash as replacement of fine aggregates in concrete.

[14] Sani MSHM, Muftah F, Muda Z. 2011 The properties of special concrete using washed bottom ash (WBA) as partial sand replacement. International Journal of Sustainable Construction Engineering and Technology. (2):65-76.