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A Review on Performance of Hybrid Asphalt Mix in Pavement Maintenance and Rehabilitation

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ABSTRACT
The importance of transportation systems and networks on the economies of the world cannot be over emphasized. Considering the prevailing severe financial circumstances; high initial budgets for annual maintenance of roadways calls for huge cost reduction. Therefore, pavements should be designed to last longer with few maintenance needs or alternatively hybrid materials utilized for maintenance and rehabilitation of pavements. This research is a review of novel studies conducted on performance of Hybrid Asphalt Mix.The various efforts to modify the performance of asphalt concrete (AC) mixtures have gained much attention and modifying effects especially as it involves recycling solid waste, appreciable reduction in pavement maintenance cost and pollution index of the environment. Introduction of additives such as Crumb Rubber Modifiers (CRM), thermoplastic polymers (High Density Polyethylene (HDPE), Polypropylene (PP), fibers, Polyethylene Terephthalate (PET),and polymers, glass fiber, etc. into asphalt improves the characteristics as well as enhances the performance of asphalt pavements. Pavement properties which include dynamic modulus, resistance to low-temperature cracking, and antireflective cracking as well as moisture susceptibility, rutting resistance are undoubtedly effectively improved.These additives can either be used with other components to modify bitumen thereby generating a new binder or as substitute for part of the mineral aggregates. There is no doubt that these additives (most of which are wastes) and binders when effectively utilized in asphalt pavement maintenance and rehabilitation will contribute in extending the service life of asphalt pavement economically, while leaving us with a sustainable environment.

Keywords: Hybrid Asphalt, Crumb Rubber Modifier, Polypropylene, High Density Polyethylene

I. INTRODUCTION

Generally,systems are nowdesigned majorly to be sustainability-driven. Maintenance and rehabilitation of transportation networks requires environmentally beneficial as well as cost-effective processes or products. To achieve these, it require creative responses which are new and dynamic, such that maintaining and rehabilitating pavements is attained with cut backs in finance and energy cost, reduction in traffic noise and minimum environmental pollution.

The incessant increase and accumulation of environmental solid waste (particularly used plastics, High Density Polyethylene (HDPE), Polypropylene (PP), End of life Tyres (ELTs), Polyethylene bags, etc.)and the improper handling, disposal and management of municipal solid waste is a huge source of concern. More so severe climatic conditions and construction failures intensifies pressure on existing infrastructures. The upsurge of urbanization and population growths results to large volume of road traffic, these builds up excessive vehicle axle weight on road pavements and prompts the need for a corresponding increment on load bearing capacity of the pavement making it essential to extend the overall service life of bitumen by enhancing its properties.

The various efforts to targeted at improving the characteristics of asphalt-concrete (AC) mixtures and enhance their performance have incurred much wide spread attention and improving effects especially as it involves recycling solid waste, appreciable reduction in pavement maintenance cost and pollution index of the environment.The introduction of additives such as fibers, plastics, rubber, polymers, polypropylene, glass fiber, crumb rubber etc. into asphalt improves the performance of asphalt pavements. These additives can either be used with other components to modify bitumen thereby generating a new binder or as substitute for part of the aggregate.

Huang S.C. et al [**1**] opined that use of alternative (or byproduct) materials in asphalt mixtures for pavement maintenance and rehabilitation is most intricate of highway uses, as it requires carefully engineered and designed processes and not just throwing the alternative material into the mixture and blending it with asphalt. This requires the careful design of the proposed mixture itself, determining the effects of the alternative materials on the asphalt binder behavior, and the pavement into which it will be integrated and the required testing of the resultant mixture for compliance to specification.

This paper is a review of novel studies carried out on Hybrid Asphalt Mix encompassing the materials, specifications related to production, processing methods, applications, and performance on pavement maintenance and rehabilitation. Not only does the utilization of Hybrid Asphalts ameliorate problems of solid waste but it also improves pavement performance where necessary in areas as enhanced skid resistance, superior flexibility, oil and crack resistance, rutting resistance, and reduction in traffic noise.

Hybrid Asphalt can be seen as an innovative solution that involves blending bitumen with additives gotten from recycled waste materials (Plastics, Rubber, End of Life Tyres, Polymers, Fibers, Polypropylene, HDPE, Fiber glass etc.) and other components. The additives can either be incorporated as partial replacement for the mineral aggregate or for modifying bitumen to produce a mixture with improved characteristics and performance.

1.1 Bitumen

Bitumen is a heavy petroleum-based hydrocarbon. It is a complex and highly viscous mixture comprising of four major families of compounds (saturates, aromatics, resins and asphaltanes) [**2, 3**] occurring in large deposits such as oil sands and pitch lakes (natural bitumen). It can also be obtained from fractional distillation of crude oil as a residue (refined bitumen). With so much prospective properties of interest such as impermeability, adhesivity, ductility, resistance to weathering and chemical attacks, etc. [**4, 5**]It is often referred to as asphalt, which is a general road-paving material consisting of hot mixed gravel, sand, quarry dust, and other fillers in a bituminous binder. Bitumen has over the years been greatly utilized in construction of highway pavements, airfield runways and many other applications; and as such the need to enhance its performance using sustainable alternatives through various recycling techniques.**Essawy A. I et al**, [**6**] affirmed that these alternatives should blend effectivelywith the bitumen binder and improve its high temperature susceptibility without making it too vicious at mixing temperature or too brittle at low temperatures. Theyneed to be readily available, relatively cheap, easily processed, chemically and physically firm during storage, production, usage, and service.

As HybridAsphalts Pavements receives wide recognition, the incorporation of additives such as Fibers, End of life Tyres (ELTs), Thermoplasticslike Polyethylene Terephthalate (PET),High Density Polyethylene (HDPE), Polypropylene (PP), Polyethylene bags, etc. will likely increase.

II. MATERIAL USE OF RECYCLED TYRE IN ENGINEERING

The exponential growth in the number of automobiles across the globe has yielded a corresponding increase in the amount of End-of Life tyres, especially in the US, Europe, China, Japan [**7**]of which adequate disposal have been worrisome considering their volume and durability [8]. With massive worldwide outcry and criticism against landfill disposal, it has become an unpleasant choice [9]. Several recovery options for scrap tyres are available such as “energy recovery” (use as substitutes for fossil fuel), “chemical processing” (in gasification ,pyrolysis and thermolysis) or “granulate recovery” were heavy shredders are utilized to reduce the tyre into smaller sizes [10] with numerous civil engineering applications such as playground flooring, paving blocks, rubberized asphalt pavements. [**11**].

2.1 Crumb Rubber Modifier

The use of Crumb Rubber Modifier (CRM) in hybrid asphalt pavements have been a promising solution beyond providing a sustainable environment, it enhances pavement performance with reports of reduction in traffic noise, cost effective maintenance, improved abrasive resistance, superior skid and rutting resistance, and better solution for pavement cracking [**12–15**]. Amongst some of the notable works with much distinct and remarkable success are roads built using rubberized asphalt mixture which involves waste/ scrap tyre or Recycled Tyre Rubber

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Modified Bitumen (RTR-MBs). This is usually gotten from recycled End of Life Tyres (ELTs). Tyre which is a complex product consists of three core material constituents: (i) elastomeric compound (have major engineering interest), (ii) fabre and (iii) steel. The fabreand steel (usually removed through aspiration and by magnets respectively) forms the structural skeleton, while the rubber in the thread, side wall, apexes, around the liner and shoulder wedge forms the "flesh" of the tyre. [**16**]

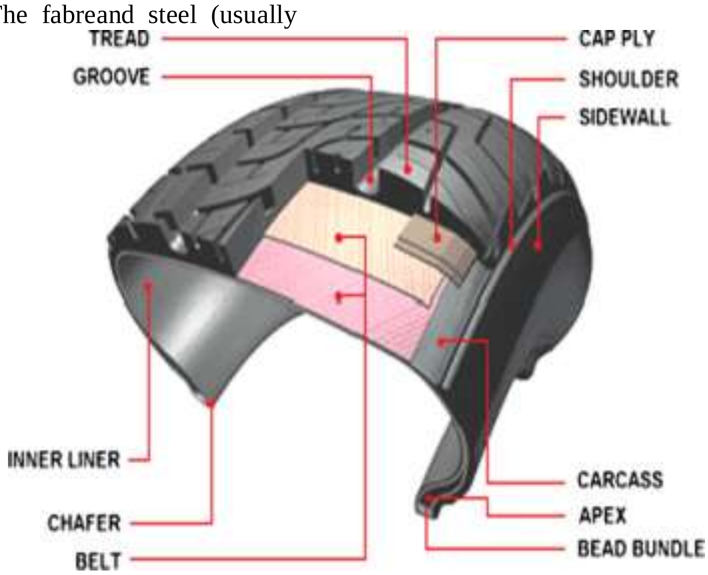

Fig -1: Tyre structure, adapted from [**17**]

Following the enhanced performance benefits, utilizing Crumb Rubber Modified (CRM) binder in blending hot mix asphalt (HMA) mixtures has garnered enormous interest with reports from different studies showing that the general performance of the mixture can be considerably affected by the amount, type and source of rubber it contains, prevailing blending conditions, particle sizes, production and, modification techniques, processing techniques in place, and so on [**18–23**]; with the beneficial characteristics of tyres such as resistance to heat and humidity, non-biodegradability vital for their pavement service roles.

Davide Lo Presti [**24**] in his work carried out a detailed study on existing technologies and specifications related to the production, handling and storage of RTR-MBs also considering their current applications within road asphalt mixtures. From expounding on the monitored procedures of reducing End of Life Tyres (ELTs) to Crumb Rubber Modifier (CRM) that are clean and consistently sized through one of the following technologies:

(i) Ambient Grinding: Processing scrap tyres at or above normal room temperature by the use of rotating blades.
(ii) Cryogenic Grinding: In this procedure, brittle RTR is obtained by freezing using liquid nitrogen (temperature between -87 to -198 °C) after which hammer mill shatters them to acquire particles with low surface area. [**25**]
(iii) Wet Grinding: Two closely spaced grinding wheels are used to further reduce the rubber particles in a liquid medium usually water. [**26**]
(iv) Hydro jet Reduction: In this technique, finer particles of RTR areobtained by further reduction through pressurized water.

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Fig – 2: Ambient Grinding of ELTs

Fig – 3: Crumb Rubber Modifier

He further explained that the subsequent conversion of CRM to Hybrid Asphalt can be by either of these two processes: One application known as **"Dry Process"** requires partial replacement of the mineral aggregates in asphalt mixture with small amounts of pulverized rubber obtained from discarded or scrap tyres (ELTs)resulting in surface paving asphalt mixture with highly improved performance. On the other hand, blending bitumen with CRM manufactured from scrap tyres and other additives, as required, before combining the binder into the bitumenous paving materials to obtain a modified asphalt pavement is referred to as the **"Wet Process"**. This produces a material with approximate representation of valuable engineering characteristics of all the base constituents.

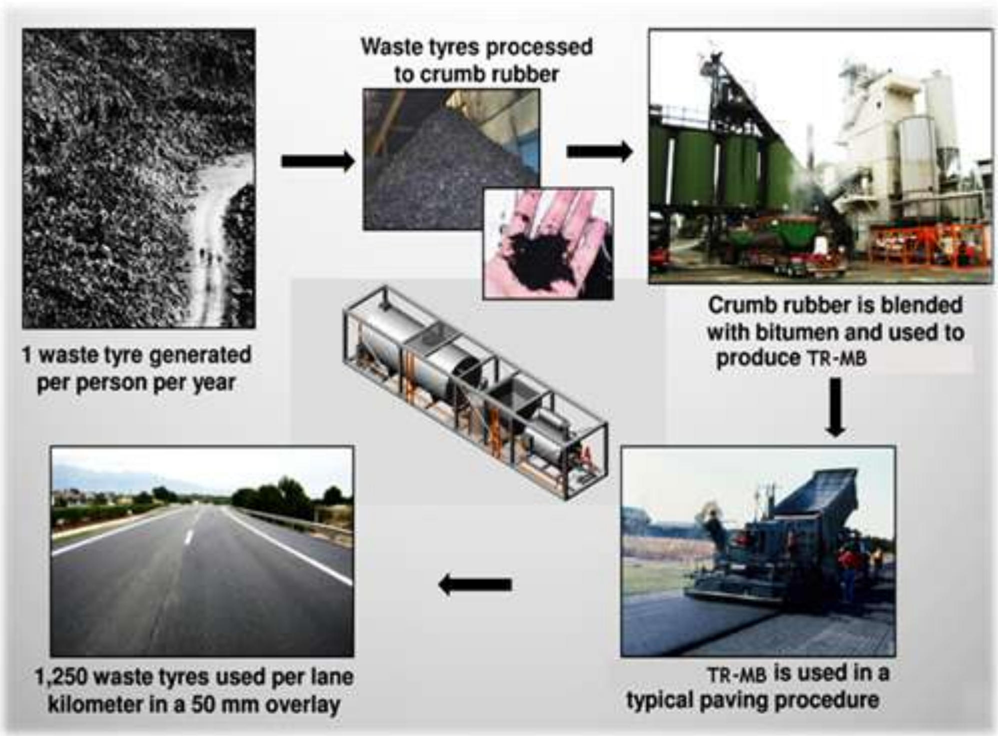


Fig - 4: Schematics of hybrid asphalt procedure from the 'wet process'

He further opined that the majorreason for using RTR-MBs is for the provision of significantly improved and sustained engineering features over normal paving grade bitumen. They can also be designed for optimum performance in any type of climate. With the rubber stiffening the binder and increasing its elasticity, the pavement resistance to permanent deformation (rutting) is increased.

Bertollo S. M [27]concurred that it can also reduce pavement fatigue, retardsreflective cracking, and impedes pavement rutting, aging deteriorationwithenhanced oxidation resistance and improved chip retention as it gives thicker binder films. **Jung J. et al** [28] asserted that hybrid asphalt pavements are highly cost effective for pavement maintenance because of the contrasting effect between the pavements and stripping.

ShengY. et al [29] reported that the performance of desulfurized rubber asphalt (DRA) consisting of several rubber powder contents was investigated under dissimilar development time and shear condition. After which super pave binder tests such as Bending beam rheometer (BBR) ,Brookfield viscosity, Dynamic shear rheometer (DSR), test conducted on different control binder samples (3 Nos. comprising of neat, 20 mesh and 40 mesh asphalt rubber binder) and a DRA binder specimen. The resultsshowed an improved stability as the ground rubber blended well and infused into the base binder. The optimaloverall performance of the DRA binder was realized at 20% (by weight) replacement of the pulverized rubber into the base binder at shear rate of 7000 r/min, 60 min shear time development time 45 min and 170 °C shear temperature,.

Table - 1: Performance of asphalt binder at different level of desulfurized rubber powder replacement

Characteristics	Percentage of Desulfurized rubber powder (%)				
	0	**10**	**20**	**30**	**40**
25°C Penetration (0.1mm)	86.3	80.2	71.3	66.8	62.4
Softening Point (°C)	46.2	50.2	53.8	57.5	55.1
Rotary Viscosity at 175 °C (Pa.s)	-	0.19	0.32	0.68	1.42
Recovery of Elasticity (%)	-	56	78	81	77
5°C Ductility (cm)	-	8.4	13.3	14.4	14.8

From **Table -2**, the DRA binder partially improved the flexibility, plasticity and viscosity of rubber beyond maintaining basic asphalt characteristics with tremendous enhancements in recovery of elasticity and storage stability penetration, softening point, recovery of elasticity storage stability and ductility.

Table - 2: Constituent properties of the base and rubber blended binders

Test Items		**DRA**	**KLMY90# base binder**	**Asphalt Rubber (20 Mesh)**	**Asphalt Rubber (40 Mesh)**
25°C Penetration (25°C)/(0.1mm)		66.8	86.3	65.6	60.1
Softening Point /(°C)		57.5	46.2	50.8	52.3
Storage stability segregation, softening point difference at 48 h/°C		1.1	-	2.4	2.3
Recovery of Elasticity (25°C)/ (%)		81	-	53	64
Rotary Viscosity at 175 °C /(Pa.s)		0.68	-	2.33	2.56
Density (15°C)/(gcm^{-3})		1.038	0.981	1.034	1.033
Rolling Thin Film Oven (RTFO)	Mass Loss /%	0.3	0.02	0.4	0.4
	Penetration ratio (25°C)/%	85	75.9	76	81

Ductility (10 °C)/cm	44	26.8	37	38
Ductility (5°C)/cm	14.4	-	6.7	12.1

The results shown in **Table-3** indicated that an increase in desulfurized-rubber powder content (up to 20%) resulted to a corresponding value rise in Immersion Stability,Marshall Stability and Residual Stability beyond which there was a decrease in the values. The same trend was observed with Dynamic Stability with peak value occurring at 25% rubber powder content. This invariably will increase rutting resistance of the asphalt pavement.

Table - 3: Performance of DRA mixture at different desulfurized rubber replacement levels.

Desulfurized rubber power content	**0%**	**15%**	**20%**	**25%**	**30%**
Dynamic Stability (cycle•mm^{-1})	1820	3096	3415	3503	3578
Marshall Stability (KN)	8.5	10.6	11.3	10.2	9.5
Residual Stability (%)	79.1	82.4	85.8	77.8	75.6
Immersion Stability (KN)	6.4	8.7	9.7	7.8	7.2

In another paper **Lo Priste D.et al** [**30**] highlighted the importance of materials selection and storage stability, general properties of processing procedures and conditions on the modification process, of the final bitumen –tyre blends.Generally the behavior of resultant Recycled Tyre-Rubber Modified Bitumen (RTR-MB) obtained is influenced by the rubber source, the processing method adopted which affects the surface area of the particles generated, consequentlyinfluencing the viscosity and overall reaction rate of the bitumen-rubber binder and rubber particle size and shape (which affects swelling mechanism and binder matrix). Since the McDonald wet process exhibits poor stability during elevated temperatures storage and modifying exiting asphalt plants will lead to high initial costs, the use of "terminal blends" or "field blends" are proposed.

Toshiaki Hirato et al (2014)[**31**] developed a high stability asphalt concrete using a thermoplastic hybrid binder comprising of polymer modified asphalt anddistinctive additives. This having high oil, flow, water and abrasion resistance which they compared with semi flexible and epoxy asphalt pavement.

Oil Resistance:

From the residual strength assessment obtained from Marshall Test carried out after immersing the test specimen in 20°C kerosene for 48hrs, shows that the high stability asphalt concrete, semi-flexible and epoxy asphalt exhibited ratio of residual strength higher than 80%, therefore indicating high oil resistance.

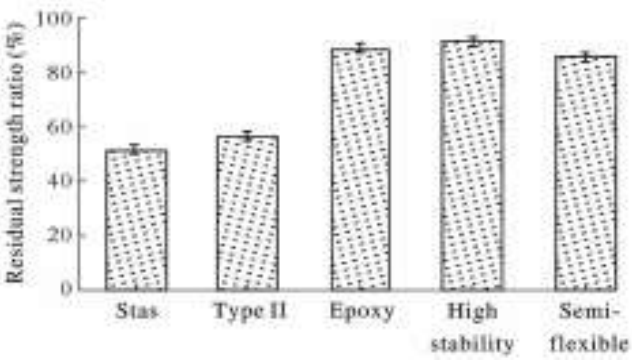


Fig –5: Results of Oil-Immersion Marshall Test

A verification test conducted on the constructed pavement to examine its oil resistance required spraying about 200g of kerosene which is prevented to vaporize on a non-woven fabric sheet spread on the pavement.

After 7 days curing, a forklift wheel (approximate vehicle weight: 3.4 tons) is steered for 20 reciprocating motions at the point without driving. **Figs. 6 and 7** shows that damage to the pavement comprising of shattered aggregates surface was recorded in the control specimen but the reverse was the case in the high stability asphalt concrete which confirms its enhanced oil resistance.

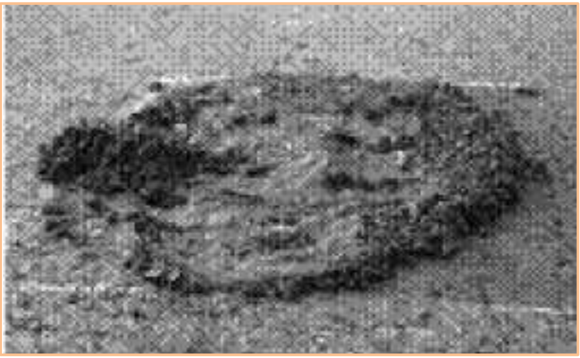
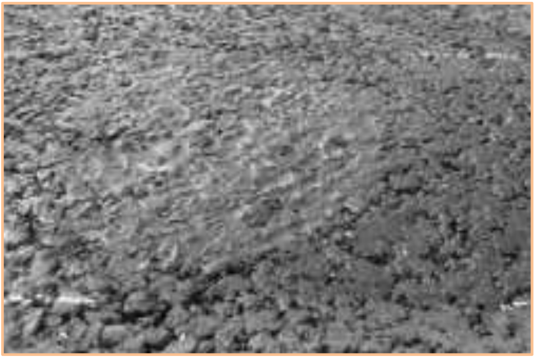


Fig – 6: Pavement surface after test (in control specimen)



Fig–7: Pavement after test (in high stability asphalt)

Rutting Resistance

Wheel tracking test was used to assess the rutting resistance. The high stability asphalt concrete showed a high dynamic stability equivalent to that of semi-flexible pavement.

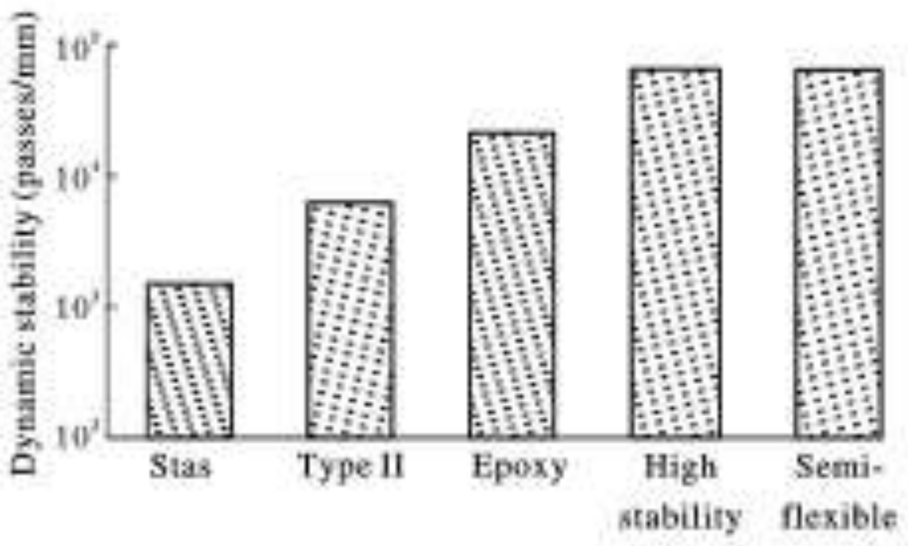


Fig – 8: Results of Wheel Track Test

Other Performances:

Results obtained from the simple bending test conducted, water-immersed wheel tracking test and raveling tests which relates to pavement flexibility, sustained water and abrasion resistance shows a high performance of the high stability asphalt concrete comparable to the PMA Type II, Epoxy and semi-flexible pavements as can be seen in **Table – 1:** below.

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Table – 1:Other Performance of Mixtures							
Performance	Test	Item Measured	Type II SMA (13)	Epoxy SMA (13)	High Stability SMA (13)	Semi-Flexible	Requirement
Flexibility	Simple Bending	Strength at Fracture Mpa)	9.8	11.0	11.3	8.2	-
		Strain at Fracture (10^{-3})	4.2	4.2	5.5	5.1	-
Water Resistance	Marshall	Residual Stability Ratio (%)	75.50	8.37	92.60	88.00	Min 75[b]
	Wheel Tracking	Stripped Area Ratio (%)	2.3	0.0	0.0	0.0	Max 5[c]
Abrasion Resistance	Raveling[a]	Abrasion Loss (cm^2)	0.5	0.3	0.3	0.3	Min 0.7[d]

Note: [a]Test condition: side chain, test temperature: -10°C, [b]Japan Road Association 2006; [c]Shimeno 2010; [d]Nippon Expressway Research Institute Company Limited 2012.

Essawy A.I et al[**6**]incorporated selected industrial wastes such as polypropylene and polyester fibers in preparing environmentally sustainable hot mix asphalt (HMA) for paving, utilizing normal and highly porous aggregates for the solid materials. Hybrid binders consisting of 5% and 10% replacement of discarded polymers were used in the asphalt. Testswere carried out on the physical and chemical characteristics, aging, scanning electron microscopy (SEM) and thermo-gravimetric analysis (TGA).The performance of the test specimens were compared with two specimens of asphalt concrete of penetration grade 60/70 as detailed in **Tables – 2 and – 3**.

Table – 2: Physical properties of the improved asphalt 60/70 (AC_1)

Characteristics	Virgin asphalt AC_1	Modified asphalt with PP 5%	PP 10%	PE 5%	PE 10%
Softening point (ring and ball), ^{0}C	50.6	60	68	80	88
Specific gravity (at 25 ^{0}C).	1.02	1.03	1.032	1.038	1.042
Penetration Index (P.I)	-0.54	0.49	1.46	2.83	3.12
Aging (Penetration after 5 h)	17	15	9	12	5
Brookfield viscosity (at 60 ^{0}C), C.P	115.7	216.3	694.3	580	1010. 3
Penetration (at 25 ^{0}C, 100g, 5 s) 0.1 mm	62	40	28	27	17

The results revealed an enhancement in the general performance of the modified asphalt over the control specimens.

Properties such as **softening point**, **specific gravity** and **dynamic viscosities** increased while **penetration value, rate of aging (hardening)** decreased with the rise in polymer content from 5% to 10% replacement. The polymer modified asphalts yields specimens which are less vulnerable to temperature. Increase value of the **Penetration Index** increases the asphalt samples resistance to low temperature induced cracking and to permanent deformation (rutting) at high temperature of the resulting pavement [**32**].

Table – 3: Physical properties of the modified asphalt 60/70 (AC_2)

Characteristics	Virgin asphalt AC_2	Modified asphalt with			
		PP		PE	
		5%	10%	5%	10%
Brookfield viscosity (at 60 ^{0}C), C.P	95	180.4	492.6	408.9	830.2
Softening point (ring and ball), ^{0}C	48.5	56	68	77	86
Specific gravity (at 25 ^{0}C).	1.019	1.027	1.03	1.036	1.04
Penetration (at 25 ^{0}C, 100g, 5 s) 0.1 mm	65	42	30	29	19
Penetration Index (P.I)	-0.97	-0.25	1.28	2.57	2.83
Aging (Penetration after 5 h)	35	24	22	18	11

In a separate paper, **Sayyed M. H et al** [**33**] studiedthe idea of hybrid reinforcement of asphalt concrete mix using glass fibers and polypropylene (PP).As a way of improving bitumen characteristics and performance, they maximizing the sticky appearance of PP fiber within its melting point value, blended it with bitumen at different percentageswhile the high modulus glass fiber was used to partlysubstitute the mineral aggregates. The samples were subjected to Marshall, softening point, Specific Gravity, penetration, and ductility tests.

From the results when compared with the unmodified sample, the penetration (which measures the depth to which a standard loaded needle will penetrate) and ductility of the enhanced bitumen was reduced, while softening point value increased by increase in the Polypropylene (PP) fibers.

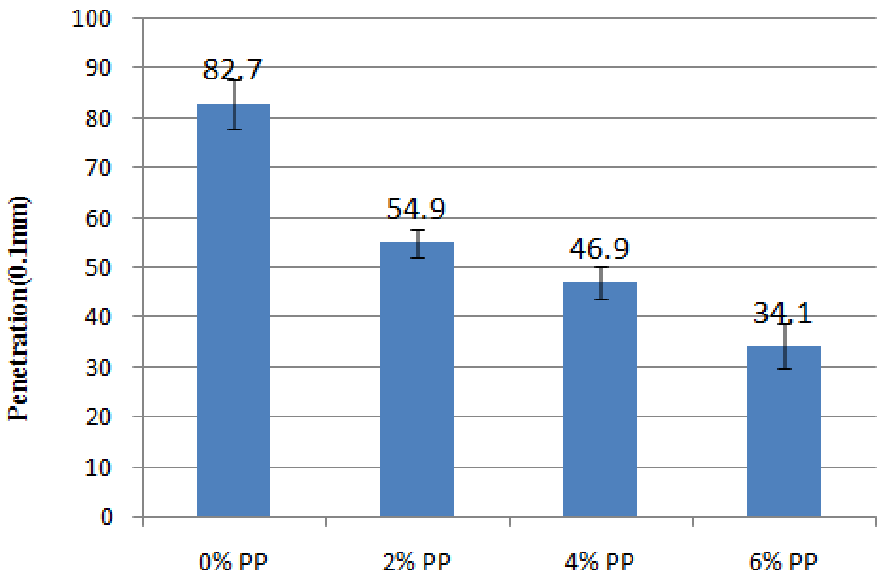

Fig – 9: Penetration test result for polypropylene modified bitumen and unmodified.

This shows that the hybrid sample is much stiffer that the control specimen, suggesting a higher resistance to rutting.

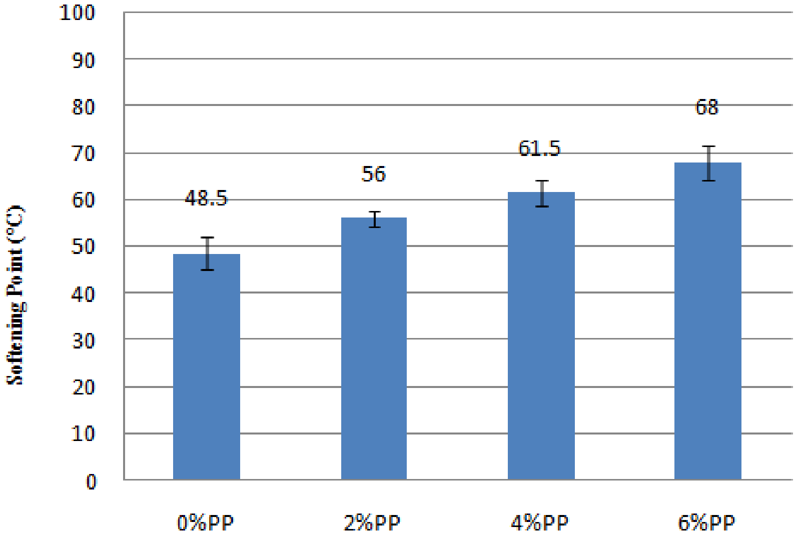

Fig – 10: Softening test result for unmodified and polypropylene modified bitumen

The increase in softening point suggested lower temperature vulnerability for the modified bitumen and as such less prone to traffic-induced deformation.

Table – 4: Ductility test results for PP modified bitumen andunmodified.

Treatment	0% PP	2% PP	4% PP	6% PP
Ductility	100 cm	46 cm	36 cm	33 cm
St. Dev.	3.70	3.44	3.58	4.10

The result of the ductility test can be attributed to the placement of the PP fibers in the bituminous specimen cross-section during the process of elongation. This increases the modulus of elasticity of the modified bitumen and further resistance to external load.

Marshall Stability Test

Marshall Stability test results distinctively clarifythe significant impact PP has on the characteristicsof the asphalt and enhance the consistency of the mixture.

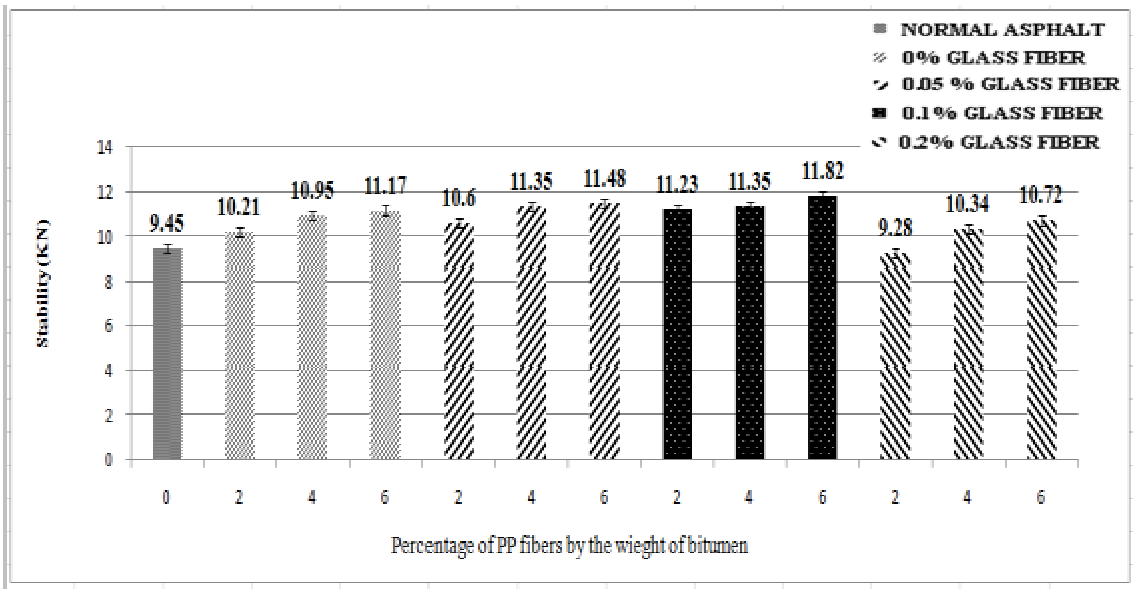

Fig – 11: Stability for different replacement of glass fiber (0.05, 0.1 & 0.2%) and polypropylene (2, 4 & 6%)

Appiah J. K et al [**34**] blended thermoplastic polymers, namely High Density Polyethylene (HDPE) and Polypropylene (PP) into conventional AC-20 graded bitumen at various plastic compositions, withan objective to enhance its properties and performance. Testingfor basic rheological parameters such as penetration, ring and ball softening point, and viscosity in the samples shows an improvement in the viscoelastic behavior of the bitumen and change in its rheological properties. The fibers exerted different degrees of influence on the bitumen, decreasing penetration value, increasing softening point and improving total dynamic and absolute viscosities of the resultant binder by forming more complex internal structure [**35, 36**].The results are consistent with the views of **Essawy A.Iet al** [**6**] and **Sayyed M.H. et al** [**33**].

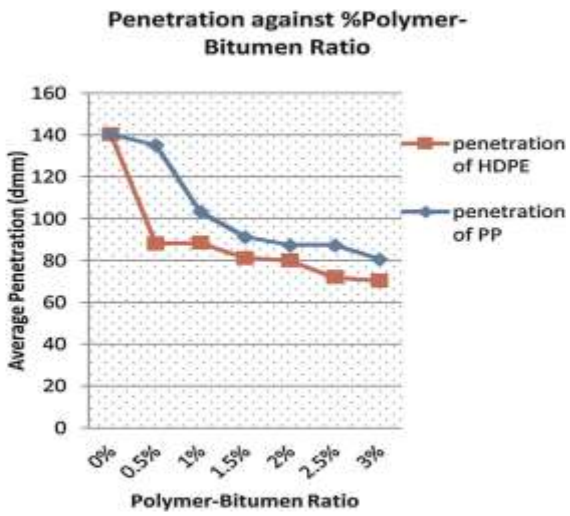

Fig – 12: Penetration graph of HDPE vs. PP

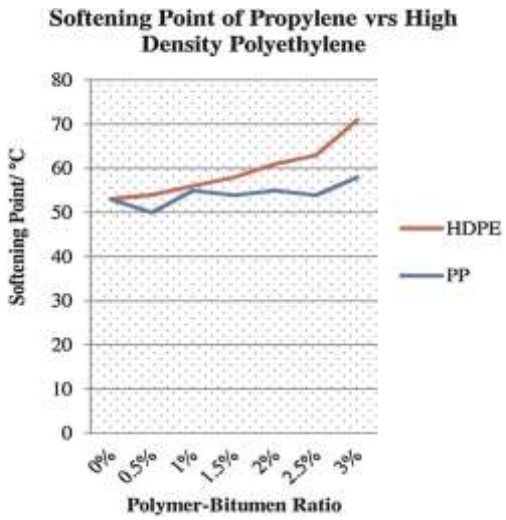

Fig – 13: Softening point of HDPE vs. PP

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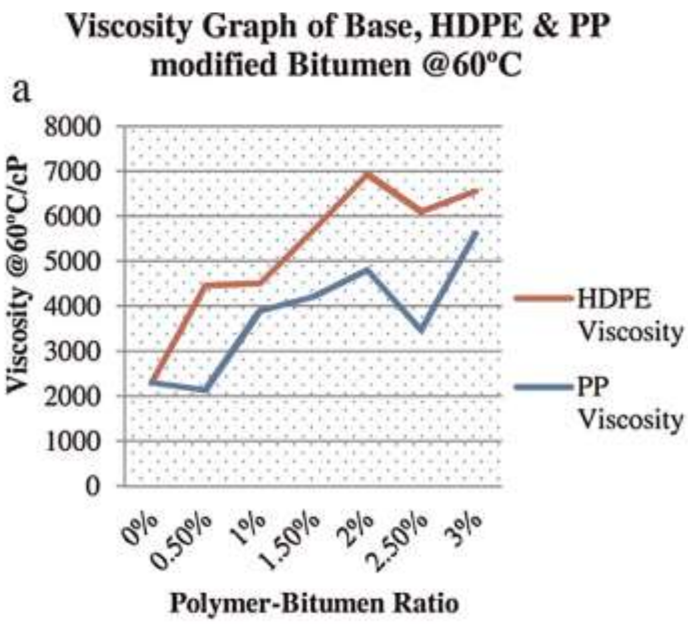

Fig – 14: Viscosity graph of Base, HDPE & PP modified Bitumen @60°C

Rahman W. A. et al [**37**] evaluated the optimal quality, handling and effect of usage of recycled Polyethylene Terephthalate (PET) as partial replacement for mineral fine aggregate in hybrid asphalt mixture. To determine the variation in permanent deformation and stiffness behavior, theyutilized the Repeated Load Axial Test (RLAT) and Indirect Tensile Stiffness Modulus (ITSM) test.From their findings, it was revealed that 20% replacement with recycled PET is ideal as it improves the permanent deformation of the asphalt mixture which enhances **rutting resistance** of asphalt pavements. Nonetheless the resilient modulus value of the recycled PET modified asphalt was less than the unmodified asphalt which shows a reduction in the stiffness properties of the asphalt. This is similar to the conclusions of [**38**] and [**39**]

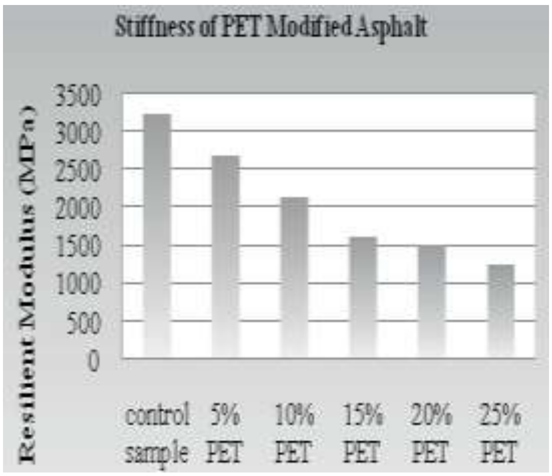

Fig - 15: Resilient Modulus of Control specimen and PET Modified Asphalt Mixture

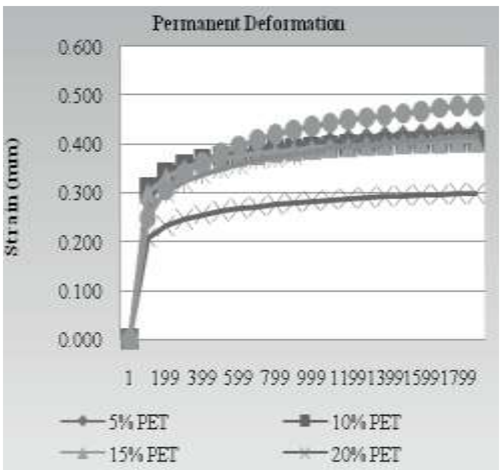

Fig –16: Permanent Deformation characteristics of Control Sample and PET Modified Asphalt

III. ENERGY CONSUMPTION OF HYBRID ASPHALT

Feipeng X., Amirkhanian S. et al [**40**] evaluated the energy demand, consumption and environmental impact assessment of rubberized asphalt pavement during the life cycle from material production, construction, maintenance and end of life. With lower consumed energy during maintenance phase, similar greenhouse gas (GHG) emissions with those of hot mix asphalt but significant lower CO and CH_4 emissions, remarkable reduction in noise,rubberized asphalt pavement is a technology to embrace for a sustainable environment.

Pavement life cycle comprises of five major phases which are materials production, construction, service, maintenance and end of life [**41**]. With each phase exhibiting energy consumptions and emissions as detailed in **Fig- 2**, the material production and construction tends to be higher. Enormous energy is required to achieve the predetermined binding temperatures for the rubberized asphalt mixtures. [**42**]. Production of asphalt mixtures every year all over the world requires an estimate of 1.36 $x10^8$MWh in energy [**43**]. This huge energy consumption represents large greenhouse gas emission. Several studies suggested that with enormous reduction in raw materials requirement and extended service life, rubberized asphalt is ideal in energy saving. [**44 - 46**].

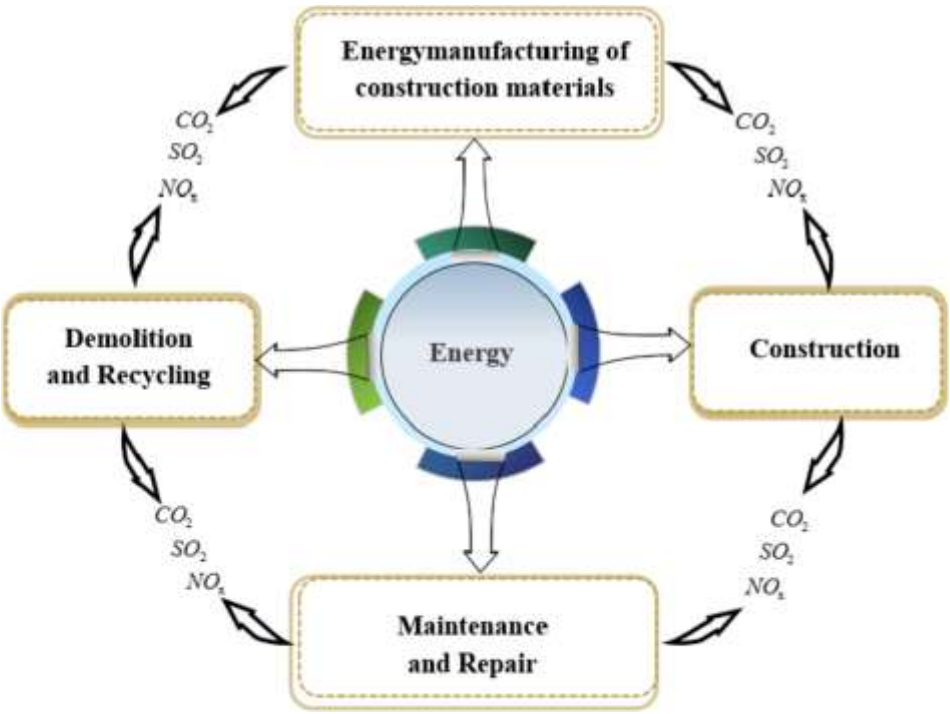

Fig – 17: Highways life cycle energy and environmental impacts assessment relationship [**47**]

Table - 5: Basic material and process energy consumption (MJ/t)

Source Material	**Athena** [**48**]	**Corti et al** [**49**]	**Frischknecht** [**50**]	**Stripple** [**51**]	**Elliot** [**46**]
Nature aggregate	57.6		140	78.6	59.1
Crumb rubber modifier: Feedstock		34900			
Crushed aggregate	36		59	7.67	
Asphalt Feedstock	40200		40200	40200	
Asphalt Manufacturing	5320		9000	2890	814
Asphalt Mixing Plant: Hot mix asphalt	531			551	2015
Crumb rubber modifier: Manufacturing		42700			
Asphalt Mixing Plant: Rubberized hot mix asphalt	375			404	

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IV. ENVIRONMENTAL IMPACT OF HYBRID ASPHALT

As regards to environmental sustainability, Hybrid Asphalt beyond providing judicious use of waste materials, their production and applications in pavement maintenance and rehabilitation presents numerous issues from waste generation and accumulation, to improper handling and discharge into water and finally emission to air.

4.1 Hazardous Emission

With several studies been carried out,results indicate that greenhouse gas (GHG) emission of asphalt rubber is higher than what is obtainable forStyrene- Butadiene Styrene (SBS) modified asphalt [**52**].

Stout et al[**53**] studied in comparison the environmental greenhouse gas emissions owing to the blending of crumb rubber to asphalt cement and that derived from the batching and production of conventional asphalt concrete. The result is highlighted in **Fig. 9.**The emission generated from the processes of manufacturing of rubberized asphalt is comparable to that obtained from hot mix asphalt; however the emission of Carbon (II) Oxide (CO) and Methane(CH_4) was lower for rubberized-asphalt mixture. Alsoexposure to hybrid asphalt does not increase health risk of those handling it.

Jones D, et al[**54**] affirms this through his studies incorporating RTR-MBs with the Warm mix techniquewhich shows anenormous decrease in emission generation during field operations due to asignificant decrease of the mixing, compaction temperatures and handling. Despite that environmental concerns upon the widespread usage of the wet process procedures still exist, but the development of novel technologies is proving that this issue can be reducedconsiderably.

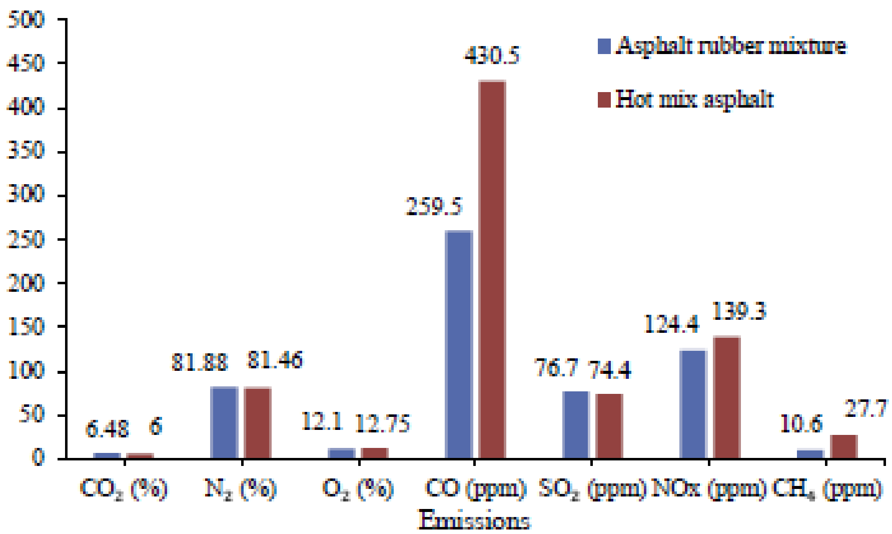

Fig - 18: Emissions generated during the production of asphalt mixtures [**53**].

1.2 Traffic Noise Reduction:

Noise pollution can be seen as the occurrence of invasive, offensive and needless sounds that have serious impact in the mind, affecting man's mental and physical health with possible adverse effect such as palpitating heart rate, excessive pressure, insomnia, probable loss of hearing and dysphoria [**55**]. Several studies have revealed the enhancedoverall performance of rubberized asphalt in reducing traffic noise with 40 – 88% when compared with ordinary pavement [**56 - 59**]. With the first successful application in highway noise reduction investigated in Brussels, Belgium, in 1981 after which other countries like Canada, Austria, America, France, Germany and Italy have adopted. [**60**]. [**61**].**Table – 9** summarized its successful application in diverse countries and regions.

Table - 6: Traffic sound investigation using rubberized asphalt and resultant noise reduction [**61 - 63**].

Country	Noise Level Reduction	Country	Noise Level Reduction
Belgium	8-10dB (65-85%)	Phoenix, AZ	10 dB (88%)

Canada	Shown Noise reduction	Tuscon, AX	6.7 dB (78%)
France	2-3dB/ 3-5 dB (50 - 75%)	Sacramento County	7.7 dB
Germany	3 dB (50%)	Orange County	3- 5 dB on Open Graded Asphalt
Austria	3 +dB	Los Angeles County	3- 7 dB
China	Significant noise reduction	Arizona, USA	9 dB

V. APPLICATION OF HYBRID ASPHALT

From the fore-going studies, Hybrid Asphalt have been judiciously applied in several pavement maintenance and rehabilitation works to remedy pavement distresses some of which include but are not limited to:**Use as chip seals** [**64**], **stress absorbing interlayers**[**65**], **crack and joint sealants**[**66**], and in hot mix asphalt [**67**]. With extensive studies done to authenticate this technology, enhanced paving experience and performance is evident such as **durability, safety, reduced maintenance, recyclability**[**68**], **constructability** [**69**], and more especially **energy saving** potential [**70**].

VI. LIMITATIONS

The use of Hybrid Asphalts are faced with certain limitations of which efforts on advanced studies are been made to ameliorate them. Some of which are:Initial costs of setting up facilities, lack of Hybrid Asphalt Mix standards and designs, limited blending, mixing, storage and transportation equipment suitable for the elevated temperatures, unavailability of appropriate processing facilities within the vicinity of the project, lack of trained personnel for precise laboratory analyses of the raw materials and final blends which is essential in enhancing the modification process and the overall performance of the final product.

VII. CONCLUSIONS

This review paper elucidated on the enhancement of asphalt mixture by blending with different additives such as Fibers, Thermoplastics Polymers (Polypropylene, High Density Polyethylene (HDPE), Polyethylene Terephthalate (PET)), Crumb Rubber Modifier (CRM), Glass Fibers, etc. either as binder modifier or partial replacement for the mineral aggregate and the performance of the resultant hybrid asphalt in pavement maintenance and rehabilitation. In this regards, the following conclusions are made:

- Use of Hybrid Asphalts in pavement maintenance and rehabilitation is enormously beneficial as they generate cost-effective and environmentally sustainable products.
- Hybrid asphalts produce pavements with enhanced improvement in characteristics and overall performance such as **constructability, recyclability, safety**, **reduced maintenance**, **durability.**
- The material constituent of the additives, processing methods, handling, etc. affects the overall pavement performance.
- Properties such as dynamic modulus, resistance to pavement rutting, resistance to low-temperature cracking, and antireflective cracking as well as moisture vulnerability are effectively improved
- The use of Hybrid Asphalts is of great benefit in energy saving, noise reduction and environmental sustainability. Although the greenhouse gas (GHG) emission is similar to hot mix asphalt, however it has a significantly lower CO and CH_4 emission.
- The enhanced improvement in the performance of asphalt pavements generally produces an overall sustainable infrastructure as evident, therefore Hybrid Asphalts and technologies which promotes use of recycled waste materials needs to be considered as first option in pavement maintenance and rehabilitation.
- More research is recommended to be conducted in the use of hybrid asphalt in other areas, also comparing the performance of various asphalt mixtures such as Styrene-Butadiene-Styrene (SBS) modified binder, Rubber Asphalt Plastic (RAP) materials and the effects of production process in the performance of hybrid asphalt and many others. Also government policies and legislations to support the use of these technologies, investments on trainings, research and further studies will yield more effective results.

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