An Investigation of Efficient Pavements and Technology for Highway Design

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ABSTRACT

The design of highways and pavements is important in DPR projects. The pavement's satisfactory performance will result in higher savings in terms of vehicle operating expenses and travel time, which will have an impact on the project's overall economic feasibility. We investigate the appropriate pavements and benefits of green pavements for highway design. Also, we investigate the applications of technologies such as green technology, energy harvesting technologies and remote sensing techniques for design of efficient pavements and its management and assessment. Further, we propose COVID 19 generated waste can be used to improve ductility, flexibility and strength of pavements. Also, we identify the various pavement design methods.

Keywords: COVID-19, efficient pavements, energy harvesting technologies, face mask, green technology, green pavements, highway, permeable pavement, remote sensing techniques.

I. INTRODUCTION

The last century has seen an escalated interaction of urbanization in rural just as metro cities. This has driven for a need of quick construction of roads and transportation infrastructure. The interest for better roads and services required researchers, designers and builders to investigate creative and cost effective designed items to fulfill expanding request that would streamline the construction just as increment durability. Pavements are fundamental highlights of the urban correspondence framework and gives productive methods for transportation [1]. Road asphalt (being adaptable or black-top asphalt, dominating around the world) is perhaps the most costly component of road construction, aside from the bridges and viaducts. Likewise, during support tasks, road asphalt is the component where more cash is ,being spent, necessitating that its plan ought to be finished with the most exact methods thinking about existing traffic conditions, conditions of climatic and materials[2]. Pavements are designed and constructed to provide long-lasting all-weather travel surfaces for the safe and quick movement of people and goods while also providing an adequate level of comfort to users [3]. The objective of this study is to identify the cost efficient pavement and technologies for highway design. Also, the benefits of green technology and methodologies for pavement management and assessment are investigated.

The rest of this paper is organized as follows, section II describes about the efficient pavements for highway design, green pavements, Permeable pavement and use of COVID 19 single use face mask for pavements applications, section III presents about the technologies and techniques used in pavements design, Also the design methods for various pavement. Finally section IV presents about conclusion and also reference used.

II. Efficient Pavements for Highway

A highway pavement is a structure made up of stacked layers of processed materials over the natural soil sub-grade, the principal function of which is to disperse applied vehicle loads to the sub-grade. The pavement takes all of the traffic loads that come down the road. Depending on the traffic requirements[4], many types of pavements might be used. Improper pavement design leads to early pavement failure, compromising ride quality as well. The pavement structure should be capable of providing an appropriate riding surface, suitable skid resistance, attractive light reflecting properties, and low noise pollution. The ultimate goal is to ensure that the transmitted stresses caused by wheel load are suitably decreased so that they do not exceed the subgrade's bearing capability. Pavements are needed for smooth, safe and systematic passage of traffic and these can be obtained by proper design of pavements.

Pavements are categorized into three types based on their behavior: flexible pavements, stiff pavements, and semi rigid pavements [4].

Flexible pavements: These are pavements with very low flexural strength. They direct the load that comes over them to the lower layers via grain to grain contact.

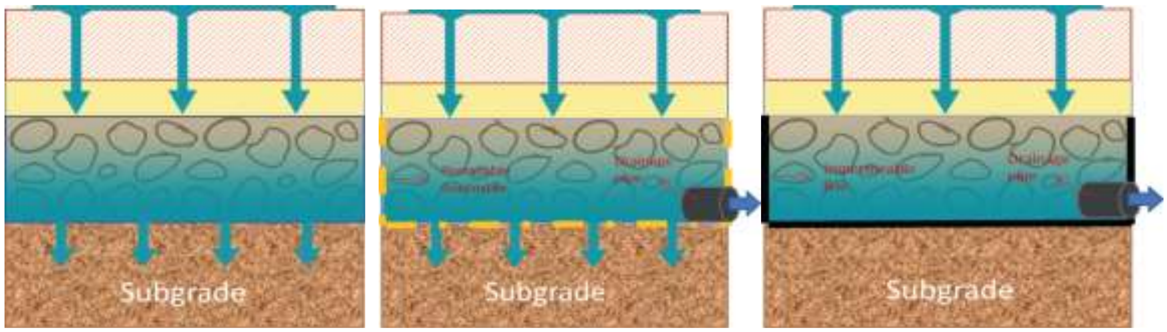
Rigid Pavements: These types of pavement have a high flexural strength and can transfer loads from the upper layers to the lower layers via slab action of the various layers.

If the base has an undulating surface, the rigid pavement will not distort like the flexible pavement. Rigid pavement is classified into four types. such as jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), Continuous reinforced concrete pavement (CRCP) and Pre-stressed concrete pavement (PCP)

Semi Rigid Pavement: These pavements have appropriate flexure strength because they are built with ingredients such as pozzolana concretes, lime-fly ash-aggregate mixes, or lean cement concrete. They have flexural strengths that are intermediate between rigid and flexible pavements.

Permeable pavements: Permeable pavement systems on the other hand are an essential component of sustainable pavements. The use of permeable pavements aids in the elimination of surface runoff on rainy days and improves water sustainability. Further the mechanical strength and durability of permeability pavements can be improved with the use of advanced materials with the least clogging effect[5].

Permeable pavements can help to restore the natural hydrological cycle, reducing the risk of urban flooding and the urban heat island effect. In general, permeable pavements are created by using porous materials with big spaces to allow rainwater to percolate through the pavement surface. Figure 1 shows the typical permeable pavement sections.



(a) (b) (c)

Figure 1: Typical permeable pavement sections: (a) fully permeable pavement, where water can infiltrate to subgrade; (b) half permeable pavement, with some water infiltrating to the subgrade, most is stored in the pavement structure; (c) permeable pavement with no water infiltrating to the subgrade but is stored in the pavement structures[8].

In the case of a rain, water can swiftly penetrate through the pavement structure into the subsurface, reducing the load on the urban drainage system and facilitating natural cycle water supply [8]. Meanwhile, water evaporation can remove excess heat from the pavement structure, minimizing the urban heat island effect. Permeable pavement systems are particularly ideal for use in residential, commercial, and industrial locations with modest traffic loads due to their better environmental friendliness.

a) Green Pavements : reuse of plastic waste in asphalt mixtures

Nowadays, because of its large volume and rapid expansion, the disposal of plastic garbage is a major concern around the world. Recycling this garbage is one solution to this problem. This option minimizes the amount of net discards, conserves both material and the energy and offers a relatively simple technique to significantly reduce the overall volume of solid waste. The utilization of recycled plastics in asphalt mixtures is a realistic option that helps to reduce plastic waste while also protecting the environment [6].

Green pavement, also known as Grass Surface, is a porous and permeable pavement that absorbs rainwater rather than resisting it. It permits water to return to the earth, preventing oil, gas, and pesticide residue from washing into the sewer. Through a comparative laboratory study, these design options are also environmentally beneficial in terms of the impact of recycling different percentages of urban and rural plastic trash by adding them in a dry process on an asphalt mixture. The use of permeable pavements results in "green" solutions. Pavers can be found in many residential areas and metropolitan locations. It is utilized for access lanes, alleys, parks, and parking lots in addition to drive Green pavement is ideal for running lanes as well as bike routes. When compared to traditional flexible pavements, the use of waste plastic (disposed in oceans, landfills, etc.) in flexible pavements produces good results. Table 1 shows the various waste plastics and their origins, whereas table 2 shows the features of dense graded mixes. Plastic pavement is more durable than flexible pavement and can endure heavy traffic. The use of plastic mix reduces bitumen percentage by 10% while increasing road performance and strength.

Table 1 Various waste plastic and sources [6]

Waste Plastic	Origin
Low-Density Polyethylene (LDPE)	Carry bags, sacks, milk pouches, bin lining, cosmetic, and detergent bottles.
High-Density Polyethylene (HDPE)	Carry bags, bottle caps, household articles, etc.
Polyethylene Terephthalate (PET)	Drinking water bottles etc.
Polypropylene (PP)	Bottle caps and closures, wrappers of detergent, biscuit, wafer packets, microwave trays for the readymade meal, etc.
Polystyrene (PS)	Yogurt pots, clear egg packs, bottle caps. Foamed Polystyrene: food trays, egg boxes, disposable cups, protective packaging, etc.
Polyvinyl Chloride (PVC)	Mineral water bottles, credit cards, toys, pipes and gutters; electrical fittings, furniture, folders and pens, medical disposables; etc.

Table 2. Requirements for Waste Plastic MDGB Pavement Layers

Minimum stability (kN at 60°C)	12.0
Minimum flow (mm)	2
Maximum flow (mm)	4
Marshall Quotient (KN/mm)	2.5-5
Compaction level (Number of blows)	75 blows on each of the two faces of the specimen
Percent air voids	3 - 5
Retained stability (%)	98
ITS (min) MPa	0.9
VMA	16
VFB	65-75
Quantity of waste plastic % by weight of plastic	6 to 8 depending on low rainfall or high rainfall areas

The polymer coating on aggregates helps to decrease voids and moisture absorption. Plastic garbage must pass through a 2.36 mm sieve and be retained on a 600 micron sieve. The percentage of dust and other impurities shall not exceed 1%. The melt-flow value shall be measured in accordance with ASTM D 1238-2010 to determine the ability of plastic to mix with the binder, and the range shall be as follows: For LDPE: 0.14-58gm/10 min, For HDPE: 0.02-9.0 gm/10 min

b) Use of COVID-19 generated waste for pavement base/subbase applications

The COVID-19 pandemic has caused not only a global health and financial crisis, but also an unprecedented environmental impact [7]. To combat the epidemic and eliminate the environmental dangers connected with the disposal of used personal protective equipment, a multidisciplinary collaborative strategy is required (PPE). Every day, a huge amount of PPE is created and utilized around the world, which is eventually disposed of in landfills or burnt. Few researches have been undertaken to date to address COVID waste. Shredded face mask can improve ductility, flexibility, and strength. Facemasks that have been disposed of can be used for pavement base/subbase applications. Figure 2 shows the COVID-19 single-use face masks repurposed for highway pavement base/subbase.

Figure 2: Recycling the used face masks with other waste materials in highway pavements [7]

Recycling and reusing shredded face mask (SFM) and blending it with recycled concrete aggregate (RCA) for pavement construction is a novel solution to reduce pandemic-generated waste.

III. TECHNOLOGIES IN PAVEMENTS APPLICATIONS

a) Green Technologies in Pavement Applications

Green technology applications in pavements result in safe, sustainable, and resilient transportation infrastructures with lower maintenance and emergence response costs, improved travel safety, and increased environmental benefit, allowing transportation infrastructures to be independent of external power grids in the event of a large-scale power outage in a disruptive event[8]. Furthermore, an emerging trend in the construction of sustainable pavements is the use of energy harvesting technologies in permeable pavements to improve both energy saving efficiency and water sustainability. The four energy harvesting technologies for pavements are presented in table 3 and these technologies will provide us a promising future for construction of more sustainable pavements by harvesting renewable energy [9].

Table 3: Comparison of green technologies for harvesting energy from pavements[8]

Energy Harvesting Technology for Pavements	Energy conversion method	Energy conversion efficiency	Advantages	Disadvantages	Application to pavements	Technology development maturity
Solar energy harvesting	Solar energy to electric /thermal energy	Medium-high	High energy conversion rate, Abundant resources	Weather limited	Pavement Health monitoring, Powering traffic lights and signals, Pavement deicing	High
Piezoelectric energy harvesting	Mechanical energy to electric energy	Low-Medium	Energy harvesting in many designs	Relatively low energy conversion efficiency	Pavement Health monitoring, Power traffic lights and	Medium

					signals	
Thermoelectric energy harvesting	Thermal energy to electric energy	Low	Flexible applicability	Low efficiency High unit cost	Power traffic lights and signals	Low
Geothermal energy harvesting	Geothermal energy to electric energy	High	High energy conversion rate, Abundant resources	Geologically Limited, Technical challenging	Pavement Deicing, Cooling Pavement, Geothermal electricity production	High

b) *Energy Harvesting Technologies in Pavement*

Employing energy harvesting technologies in the pavements can continuously generate self contained and clean power to activate in situ monitoring sensors, and illuminate traffic lights, and signals [10]. Permeable pavements, on the other hand, can rapidly drain storm water runoff, reducing the risk of urban flooding and improving travel safety, particularly for walkways and parking lots. Energy generation from pavements is feasible and energy harvesting techniques are adaptable for different pavement conditions. Permeable pavements typically have interconnected gaps of 15% to 35% by volume, with a major hydraulic benefit of decreasing 90% of peak runoff volume. These applications not only help to improve water sustainability management by reusing urban runoff, but they also help to improve energy conservation by recovering wasted energy from pavements.

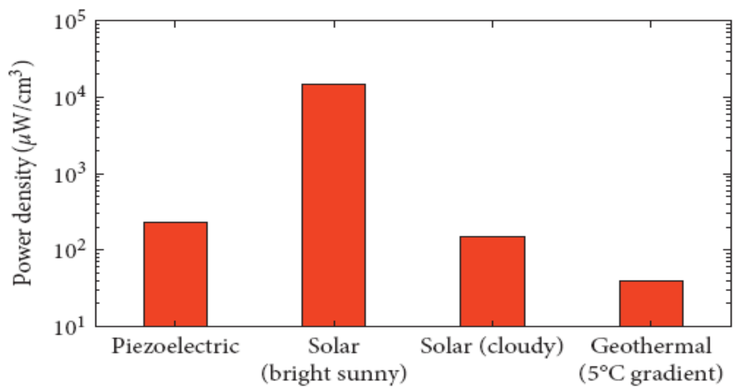


Figure 3: Power density of different green technologies [10, 11].

Some challenging issues remain for more practical applications, such as how to properly install the devices in construction, efficiently maintain the devices during their service life, and replace defective components on time. When compared to a standard pavement system, the inclusion of energy harvesting devices may have a negative impact on structural integrity, resulting in poor mechanical characteristics and crack development, which may cause internal moisture damage during operations.

Figure 3 shows a power density of piezoelectric, solar, and geothermal technologies. The electricity generated from the pavements can either be carried away for powering electric devices of signage and traffic lights, or in cold weather, deicing is performed, and pavement characteristics such as temperature, deflection, and traffic are monitored.

c) *Remote sensing Techniques for pavement Management and Assessment*

The employ of remote sensing in transportation research is becoming a significant and commercially beneficial area of investigation. The traditional methods such as coring and field surveys are utilized to evaluate the condition of transportation infrastructure. These traditional methods are expensive, labor intensive and time consuming process.

The remote sensing techniques offer nondestructive evaluation methods for road condition assessment with large spatial coverage [12]. These techniques provide new opportunities for pavement managers to analyze broad areas quickly. Remote sensing techniques are utilized to identify and analyze pavement defects and distress caused by weathering or service loads. Although remote sensing techniques will never completely replace traditional geotechnical procedures, they do provide the possibility of reducing the number or size of areas that require site visits or manual approaches. In addition remote sensing has many other applications: the utilization of multi-source and multi-spectral data can provide improved detection of infrastructure damage as well as timely information regarding the traffic ability of road networks after a disaster.

The data collected from photographs is the most commonly used remote sensing technique for pavement analysis. Geotechnical engineers have long used ground penetrating RADAR (GPR) to detect subsurface irregularities. While temperature differences detected in the infrared region can be utilized to find pavement problems and cracks, Laser scanning and hyperspectral photography techniques, for example, help to discover and locate faults and distress more quickly than human surveying. Sensors installed on various platforms collect electromagnetic radiation generated or reflected by an object or region of interest. The platforms such as moving vehicles, unmanned aerial vehicles (UAVs), airplanes and satellites are used to gather remote sensing data. These platforms are employed to implement remote sensing techniques. Sensors, in addition to many platform possibilities, utilise distinct sections of the electromagnetic spectrum to identify and detect surface and subsurface faults.

d) Pavement Design methods

The methods and considerations for pavement design are necessary in design and constructions of highway. The design of a pavement is heavily influenced by soil conditions and the amount of traffic loads that are predicted to be carried over its design life. During the structural design of pavements the major considerations are material design and thickness design of pavements. We also consider drainage design, which studies the entire structure of pavements in terms of drainage requirements and incorporates facilities to meet those requirements.

In India, flexible pavements are designed using the California Bearing Ratio (CBR) of the subgrade soil and the expected number of cumulated axles over the design life (15-20years) of the pavement or axle load spectrum to arrive at Cumulative Damage Factor (CDF) for rigid pavements. The Indian Roads Congress (IRC) method of design allows for the use of conventional as well as stabilized and recycled materials in flexible pavement layers, and the thickness of each layer is then determined using a layer theory based algorithm [13].

The most widely used design approaches/methods for flexible pavements are: Group Index (G.I) method, California Bearing Ratio (CBR) method, California R–Value or Stabilometer method, Mc-Leod method, Tri axial Test method and Burmister method. The thicknesses of rigid pavements are determined to withstand the expected damage over the design life of 30-40 years. The thickness design is influenced by traffic loading, sub-grade soil, moisture, and temperature differential. To begin, the thickness of rigid pavements is designed to allow for fatigue failure. The estimated pavement thicknesses are next analyzed for the crucial combination of load stresses and temperature stresses. The Indian Road Congress (IRC) approach is the most often utilized design method for rigid pavement. Semi rigid pavements are designed in the same way as flexible pavements, but with some correction factors incorporated, or they are designed using different methods [14, 15].

IV. CONCLUSION

We successfully carried out the investigation to identify the cost efficient pavement and technologies for highway design. Also, identified the benefits of green technology and techniques for pavement management and assessment and also we have been investigated the pavement design methods. Further, we have investigated the COVID 19 generated waste can be used to improve ductility, flexibility and strength of pavements.

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