gcca India

Global Cement and Concrete Association

BENEFITS OF CONCRETE ROADS OVER BITUMINOUS ROADS

2022

INTRODUCTION

Roads play a vital role in the transportation network, and directly impact economic prosperity, societal well-being, and community development. Broadly, two types of pavements are used in India for the construction of different roads, viz. the flexible pavement (or bituminous pavement) and the rigid pavement (or concrete pavement). Properly designed rigid pavements built primarily with an appropriate concrete mix can provide many decades of service with little or no maintenance, meeting the aspects of sustainable development goals of a project or the nation; the first concrete pavement in the world was constructed in 1872 in Inverness, Scotland, and is still in use today [1]. The Government of India clearly emphasizes infrastructure development for an economic upswing, and to achieve this goal, building 100 smart cities and upgrading 125,000 km of road length has been envisaged over the next five years as per the Union Budget of 2019–2021. The Smart City initiative by the Government of India's Ministry of Urban Development (MoUD) promotes the application of sustainability concepts to the transport network. Most megacities are considering concrete pavements over bituminous ones for urban connectivity. This is in line with the evolution of road construction with time keeping user safety, cost-effectiveness and vehicle efficiency in view.

India has the second-largest road network in the world, currently spanning close to 6 million kilometres (km) [2]. This road network transports 64.5% of all goods in the country and 90% of India's passenger traffic uses this network to commute [2]. The total length of national highways is expected to reach 200,000 km by 2022. Several National and State Highways are currently undergoing major transformations. Premier road projects, such as the Bharatmala Pariyojana, dedicated economic corridors, Inter corridors of feeder routes for improving the effectiveness of economic corridors, in addition to the programs, the development of ring roads/by-passes and elevated corridors to decongest traffic passing through cities and enhance logistic efficiency, demonstrate the importance that the Government attaches to the development of good road networks. The potential of the road infrastructure's contribution to the growth of the country is tremendous, and the use of concrete for road construction could help in meeting the sustainable development goals of the nation.

1. ROAD CONSTRUCTION

Pavements are typically constructed in distinct layers composed of blended-materials such as asphalt, cement concrete, soil, etc. Due to the connectivity that it leads to and the opportunity for jobs, especially for the unskilled labour force, the road construction industry is a significant contributor to the socio-economic development of any nation. However, the negative impacts of construction activities on the environment and human health are also evident. A typical flexible pavement consists of a proper, well-compacted layer/layers of asphalt, which is a mixture of aggregates and bitumen [3], resting on a bed of granular material. It can be constructed over deformable base layers, and can immediately be opened to traffic after construction. More than 95% of all the all-weather roads have this pavement type.

Rigid pavements are designed for a longer life span than flexible pavements, and generally require a higher degree of base preparation and quality control. Such pavements are made mostly of concrete [4] – either plain or reinforced; portland cement is used as a binding material, mixed with coarse aggregates, sand, water, supplementary cementitious materials, fillers and admixtures to yield a mix having adequate strength and durability properties. The load transfer in rigid pavements is through slab action against grain-to-grain interlocking in flexible pavements, which enables the transmission of wheel load stresses through a wider area with a small depth below [5], in the former. This minimizes the need for multiple layers, in comparison to the flexible pavement. Consequently, the demand for aggregates, and raw materials in general, in rigid pavements, is much less. Furthermore, in the long run, the concrete pavement could be more beneficial in terms savings of natural materials, energy consumption and environmental impacts. The use of industrial and agricultural by-products, such as quarry dust and fly ash, increases the sustainability of rigid pavements (see details provided in the Sections 4 and 5).

Government departments like the State Public Works Units, National Highway Authority of India, Municipal Corporations, local bodies, etc., have recently opted for concrete pavements, as an alternative to the conventional flexible pavements, most importantly, due to the longer service life with low maintenance costs. Also, the higher reflection of radiation due to the lighter colour reduces the urban heat island and the intensity of artificial lighting for night-time visibility, which directly reduces the electricity demand. However, bituminous pavements are widely preferred due to the short-term cost saving, and faster pace of road construction, without taking the long-term advantages over the life cycle of the road into consideration. It must be borne in mind that the overall environmental impact could, consequently, be much higher for bituminous roads. The use of concrete has proven to have benefits not only from the environmental point of view but also from the functional quality perspective. The life cycle assessment as described in Section 5 shows concrete roads can be beneficial for sustainable construction and create a more efficient transport system.

2. CONCRETE ROADS

Most concrete pavements are jointed without (most commonly used in India) and with reinforcement. Other types of concrete pavement include those made with roller compacted concrete, continuously reinforced concrete, precast concrete slabs, prestressed concrete slabs, interlocking concrete blocks, and pervious concrete, which are gaining interest also in India.

Road construction poses the challenge of delivering the best performance (in terms of enabling safety, riding quality, traffic intensity and durability, as well as possible additional functions such as drainage) as efficiently as possible. The usual parameters for measuring efficiency are resource consumption, cost of construction and road-vehicle interaction. Concrete roads offer solutions to address these challenges due to the possibility of varying its constituents, properties and construction systems. Also, concrete has excellent sustainability qualities, which have been enhanced by the significant progress (enhanced energy efficiency, waste heat recovery and clinker factor improvement) made by the cement and concrete industry in reducing CO_2 emissions, energy demand and wastage during the manufacturing.

The use of Supplementary Cementitious Materials (SCMs) and other mineral admixtures [6], along with recycled materials derived from reprocessing materials previously used in construction [7] or wastes from other industrial processes, in both the bound and unbound layers beneath the concrete road, would further reduce the environmental impact, and possibly the life-cycle costs.

In cities, such as Delhi, Chennai, Bangalore, Pune and Nagpur, concrete overlays on existing distressed bituminous roads, have been placed over long stretches. Such an overlay over pre-existing bituminous surface is known as white topping, one of the most successful pavement rehabilitation methods. This can be achieved in three ways as listed in Table 1.

CONCRETE OVERLAY TYPE	THICKNESS IN mm
Overlay – ultra-thin (UTW)	Less than 100
Overlay thin (TWT)	Between 100 to 200
Rigid pavement conventional white topping (WT)	200 or more

Table 1: Concrete overlay types [8]

3. BITUMINOUS ROADS

The bituminous or asphalt pavements, being less stiff compared to concrete roads, require more layers to safely transmit the traffic load down to the subgrade. Asphalt is a mixture of aggregates and bitumen, which is a sticky black viscous liquid obtained as a byproduct of petroleum. The asphalt is required to be heated to temperatures much higher than that of the ambient for facilitating mixing, placing and effective compaction. This results in additional Green House Gas (GHG) emissions and heat generation.

Normally, bituminous pavements have been preferred over concrete pavements due to numerous reasons, such as lower initial construction cost (bitumen was cheaper), quick road repair (in case of damage and quality issues), limited availability of cement and concrete, and unavailability of paver machines and skilled manpower. Nowadays, however, the conditions are very different. Cement supply is plentiful, bitumen prices have increased due to crude oil costs going up and the number of readymixed concrete (RMC) units has increased. Further, access to paving machinery has drastically improved, and increasing mechanization has led to faster road construction. In the cases where concrete roads need to be repaired, it can be done at a much faster pace (thanks to rapid hardening admixtures) with minimal obstruction to traffic. Also important is the reduction of dependence on imports as cement is produced abundantly in India.

3.1 Impact of the bituminous road on the environment

GHG emissions from the mixing phase of asphalt are very high and could account for about 54% of total emissions [9]. During the mixing operation of hot mix asphalt, fine dust particles may emanate from the plant and pollute the environment [10]. The life expectancy of a bituminous road is much lower than that of concrete pavements and requires periodical maintenance. Which again leads to GHG emissions. The top-wearing coat needs to be relayed periodically every two or three years further polluting the environment; in many cases, such resurfacing and filling of potholes are carried out soon after construction, especially in high rainfall areas. **Since the total emissions from the transportation sector is already of a higher magnitude, effort needs to be made to lower the same. One of the ways to do so if by shifting to more sustainable materials for constructions. Since concrete is fully recyclable, it may be adopted for most of the highway applications.**

4. BENEFITS OF CONCRETE ROADS OVER BITUMINOUS ROADS

The benefits of concrete roads can be categorized into short-term, long-term and general benefits[13]. The Life Cycle Assessment (LCA) of concrete roads against bitumen roads is described in Section 5.

4.1 Short-term benefits

- High stiffness, negligible wear & tear (due to abrasion), and higher durability.
- Fuel efficiency: Heavy vehicular movement on concrete roads can lead to higher fuel efficiency.
- Due to its grey colour, the concrete surface reflects heat, whereas asphalt pavements absorb and store this heat for longer durations leading to an increase in the surrounding air temperature (urban heat islands).
- Concrete roads (with proper cross-slope and embankment) do not get damaged due to heavy rains or oil spillage.
- Bituminous / Asphalt roads bleed at high ambient temperatures whereas concrete roads are unaffected.
- Elimination or reduction of the thickness of the underlying layers reduces the consumption of materials like stone aggregates.
- Rigid pavement construction provides an opportunity for using suitable industrial and agricultural wastes and recycled materials.
- Innovative features continue to emerge (e.g., Smart Roads, self-illuminating, EV charging roads, etc.) that result in additional enhancement to the functionality of concrete pavements.

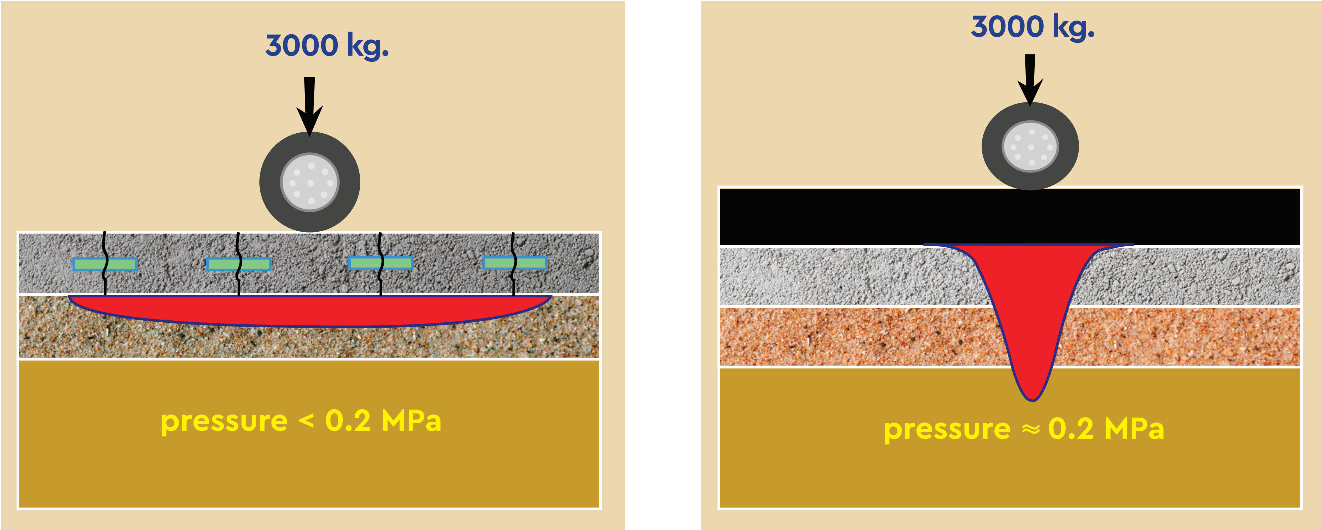


Figure 1: The rigidity of concrete spreads the load over a large area and keeps pressure on the sub-grade low

4.2 Long-term benefits

- The minimum life span of concrete roads is 20–30 years with zero/very low maintenance costs.
- Concrete roads do not require large volumes of raw materials for regular maintenance. Hence, this reduces the consumption of natural resources and transportation costs. Road downtime is reduced considerably.
- Zero potholes, good riding quality (lower roughness), and negligible road dust result in a better user experience, and lesser health issues related to air pollution.
- To improve sustainability, innovative pavement design types, such as two-lift concrete pavement, roller-compacted concrete (RCC), precast concrete and concrete pavers, and thin concrete pavement (TCP) could be considered.
- Recyclability of concrete pavements is higher and for enhancing the performance of recycled concrete pavements, SCM's could be used instead of cement and this further helps in improving sustainability. Similarly, in RCCP (Roller Compacted Concrete Pavement) a special type of concrete pavement, which is already cost-effective than flexible pavements, the use of SCMs could further enhance its performance and thus will be more sustainable.

4.3 Other benefits

4.3.1 GHG emissions reduction

Raw material extraction and clinkerisation of limestone contribute to the majority of GHG emissions in the process of cement manufacturing. This has been significantly reduced through various product innovations over the last 20 years. The use of alternative fuels helps in ensuring the increase in thermal substitution rate, which helps in lowering the overall GHG emissions, in cement production. Cement companies produce blended cements (Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) which have low clinker-to-cement ratios, resulting in lower GHG emissions per tonne of cement. Similarly, the use of recycled concrete aggregates (RCA) from C&D waste in highway construction could lower the aggregate demand; IRC:121–2017 allows the use of 30% RCA for base-layer application of concrete pavements.

4.3.2 Increased skid resistance

Pavement skid resistance is very important for safety. Concrete roads have transverse texturing and tinning on the surface, which help the vehicle to have better traction and avoid crashes, particularly in wet weather. A well-textured concrete road surface

Figure 2a. Marine Drive Concrete Road (Mumbai)- First Constructed in 1939

Figure 2b. Re-constructed as Concrete Road in 2012 after more than 70 Yrs.

reduces wet weather accidents caused by skidding and hydroplaning more effectively than a bituminous pavement surface [11].

The traditional problems with cc pavements such as noise and lower surface friction could be avoided too great extent by shifting to longitudinal tinning's. The tinning process also helps to reduce tyre/pavement noise. It is observed that the texture provided when the road is built wears off due to vehicular movement over time but retexturing can be done using diamond grinding.

4.3.3 Fuel efficiency

Tests have shown that concrete roads result in improved vehicle fuel efficiency as the concrete acts as a rigid slab and does not absorb the vehicle's kinetic energy. The higher fuel efficiency could also be due to lower roughness in concrete pavements during the service life of the road.

4.3.4 Albedo, urban heat island effect & night lighting

It is observed that a bituminous road has a low albedo[12] range of 0.05–0.20. This means that it absorbs most of the shortwave radiation from the sun, increasing the surrounding temperature. A concrete road, on the other hand, have an albedo range of 0.25–0.46 making it a better reflector of radiation than bituminous roads[13]. Therefore, concrete roads could reduce urban temperatures and improve comfort levels. Australian study showed that a concrete carriageway, being light-coloured, required only 14 light posts per kilometre as compared to 20 per kilometre for an equivalent darker (bitumen) surfaced roadway, representing a night-time lighting energy saving of 30% [14].

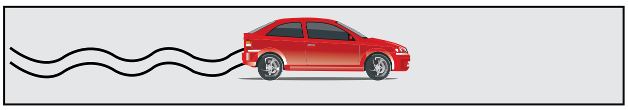
5. LCA OF CONCRETE ROADS VS BITUMINOUS ROADS

Life Cycle Assessment (LCA) is an effective method to evaluate the environmental footprint and energy demand associated with different building materials for civil engineering applications. A complete LCA (cradle to cradle) considers most of the parameters involved from the extraction of raw material, to the final construction of the structure, its maintenance and repair, demolition and recycling for re-construction. The following sub-sections highlight that concrete pavements require less material, consume less energy during road construction, are more fuel efficient and durable, and have higher recyclability potential than bituminous roads. In addition, the crushed concrete (once it reaches the end of its useful life) can absorb carbon dioxide from the atmosphere (carbon sequestration) as an additional benefit of recycling. Also, the overall life cycle cost of concrete roads is much less than bitumen roads due to higher service life and lower maintenance requirements [15].

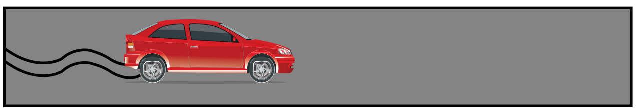
5.1 Raw material extraction

The primary raw binding material for bituminous pavements is asphalt and the binder for concrete pavements is cement. The other raw materials, coarse and fine aggregates are essentially the same for constructing both types of roads. Asphalt is produced during crude oil refining. A significant amount of air pollutants, as well as GHG emissions, are released during the petroleum refining process. Also, the energy required for the production of bitumen is significant. Cement is produced from limestone (through clinkerisation) by blending it with supplementary cementitious material and different minerals. A substantial amount of energy is required to produce

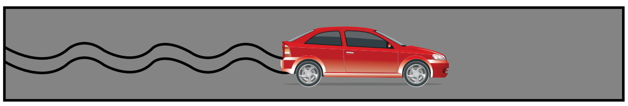
Dry Concrete Surface *162 ft* *10.8 car lengths*



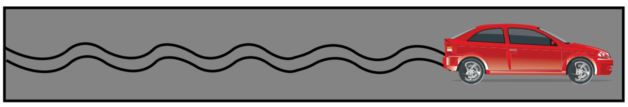
Wet Concrete Surface *316 ft* *21 car lengths*



Dry Asphalt Surface *190 ft* *12.7 car lengths*



Wet Asphalt Surface *356 ft* *23.7 car lengths*



Wet Rutted Asphalt Surface *440 ft* *29.3 car lengths*

Figure 3: The concrete road requires lesser breaking distance, results into improved commuter safety

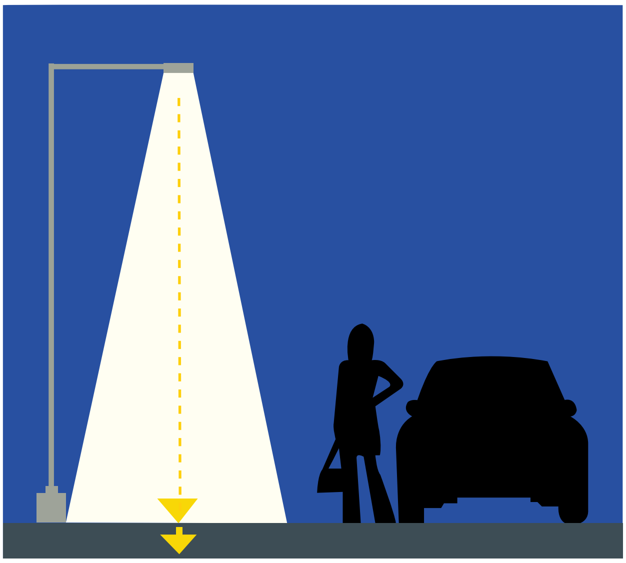
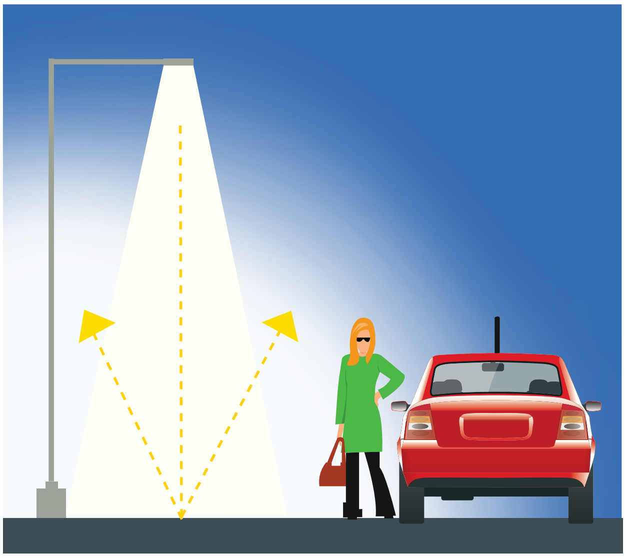


Figure 4:Heat albedo effect, 4.a. Asphalt surface



4.b. Concrete surface

clinkers, though, with different energy efficiency and fuel conservation measures, the net energy required to produce the clinker has been reduced over time.

A certain percentage of clinker is substituted by different industrial waste like slag and fly ash to reduce GHG emissions per ton of cement. Also, energy derived from alternative fuels, renewable energy in cement production, etc. helps in further reducing these emissions.

The thickness of the road (profile) required for a similar California Bearing Ratio (CBR) is relatively less for the concrete road. The average thickness of the profile for a bituminous road is 615 mm and that for the concrete road is 600 mm (refer to Table 2). This also contributes to lowering the emissions attributable to raw material extraction and processing. The Indian Road Congress allows up to up to 50% use of slag cement (by weight of cementitious material) in road construction rather than using OPC [16]. This can contribute significantly to curtailing the GHG emissions from cement manufacturing.

For the same wheel load and other conditions, the total thickness required for concrete pavement is significantly lesser than flexible pavements. Also, considering zero/ very less maintenance against periodical re-surfacing in flexible pavements, the aggregates demand is significantly lesser in concrete pavements. This scenario significantly helps in GHS emissions associated with new mining of aggregates. Also, the use of SCMs such as slag (50%) as replacement of OPC could further lower down the carbon footprints.

5.2 Construction

Asphalt produced from the Hot Mix process at a batch plant requires more energy than the concrete produced at a Ready-Mix Concrete (RMC) plant. The main reason for this is the higher energy requirements for asphalt during the construction phase. On the other hand, concrete mostly requires the raw materials (water, aggregate, and cement) to be mixed at ambient

Table 2: Typical pavement design for Highway (4/6/8 lane). Reference: Circular by Ministry of Road Transport and Highways (MoRTH) [17]

Pavement	Bituminous	Concrete
Material Composition (with thickness)	• Granular Sub Base (200 mm) • Wet Mix Macadam (250 mm) • Dense Bituminous Macadam (115 mm) • Bituminous Concrete (50 mm)	• Granular Sub Base (150 mm) • Dry Lean Concrete Base (150 mm) • Concrete Slab (300 mm)
Total Thickness	**615 mm**	**600 mm**

temperature while manufacturing. The result shows that a one-kilometer stretch of single-lane asphalt pavement requires 73% more energy than concrete pavement [18].

5.3 Operations

Emission from vehicles is one of the important factors to be considered in any study of transportation. A study shows that concrete roads are relatively more fuel efficient than asphalt roads owing to lower roughness during the service life; fuel savings could range from 3.2% to 6% on concrete roads [19] Less consumption of fuel results in lower vehicular emissions.

5.4 Repair & maintenance

The durability and resistance against water seepage are comparatively high for a concrete pavement. While the initial cost and effort for the concrete road are higher than that of the bituminous road, the maintenance and repairing frequency is much lower. The bituminous road requires more frequent repair and maintenance, including relaying of the top wearing coat over its service life. A concrete road incurs one-tenth of the repair cost per year as compared to an asphalt road, making concrete more cost-efficient overall [15].

5.5 Reconstruction, recycling & circular economy

The final stage of a concrete pavement's life cycle is reconstruction and recycling. In-situ recycling of concrete pavement, generally as a new sub-base or base layer, is a viable alternative, with the economic and environmental advantages of minimal material transportation. It is also possible to use screened Recycled Concrete Aggregate (RCA) for a new base [20]. Reclaimed Asphalt Pavement (RAP) is usually produced from the millings of an existing asphalt pavement. While the predominant use of RAP is mainly in new asphalt pavement, RAP is also commonly used in aggregate bases of the concrete pavement [21]. Similar to concrete recycling, recent developments in flexible pavements involves reusing of RAP either in HMA, cold-mixes or through foaming the adhered asphalt. However, contrary to crushed concrete which helps in sequestrating the carbon-dioxide from the environment, RAP if stockpiled in open environment could lead to acceleration of the oxidation process, leading to stiffing of the asphalt film – in this case, the potential of RAP reduces. Therefore, once removed, it becomes necessary to carefully stockpile the RAP in controlled environment.

On the other hand, concrete chunks could be stockpiled in almost any environment. Reuse of aggregates from concrete demolition waste for soil stabilization and in-situ recycling are excellent examples of the circular economy – even though they do not follow a traditional product-to-product closed recycling loop. Often, the most sustainable way to reuse aggregates from concrete demolition waste is in the road base. This is a good example of open-loop recycling – material from one application is reused in another, thus reducing the extraction of virgin material [22].

6. INITIATIVES TO PROMOTE CONCRETE ROADS IN INDIA

The Government of India has been focusing on paving highways with concrete because of the durability, lower maintenance cost and longer service life [23]. The Indian Road Congress is committed to continuing its endeavors in promoting environmental-friendly technologies and materials in road construction. It has published several guidelines for promoting recycling and lowering the environmental impact [24]. The Pradhan Mantri Gram Sadak Yojana (PMGSY) [25] has committed that all roads are to be made from cement concrete moving forward. Under the PMGSY, a cost analysis was carried out for concrete roads & bituminous roads. The initial cost, maintenance and lifecycle expenses were analyzed for a 1 km stretch of both types of roads. The results showed that though the initial cost of cement concrete roads is 28% more than bituminous roads (the use of 30% fly-ash as a replacement to cement in concrete can reduce the cost by 20%), the life cycle and maintenance cost for cement concrete roads is 19% (if 27% fly ash is used as an SCM) less compared to bituminous roads [26]. The NHAI has also shifted to concrete roads for its Bharatmala projects [27] at many stretches as also in other major road projects.

7. FUTURE OF CONCRETE ROADS IN INDIA

Both the pavement materials, concrete as well as bituminous asphalt, have their own advantages and disadvantages. However, considering the life-cycle cost, availability of local materials, and durability in harsh conditions (monsoon, unanticipated traffic), concrete pavements seem to be more suitable for Indian conditions. However, shifting from the bituminous pavements in road construction to concrete is not possible overnight. The different initiatives undertaken and their potential benefits show that concrete roads are sustainable alternatives to reduce the negative environmental impact and enhance the quality of the road network.

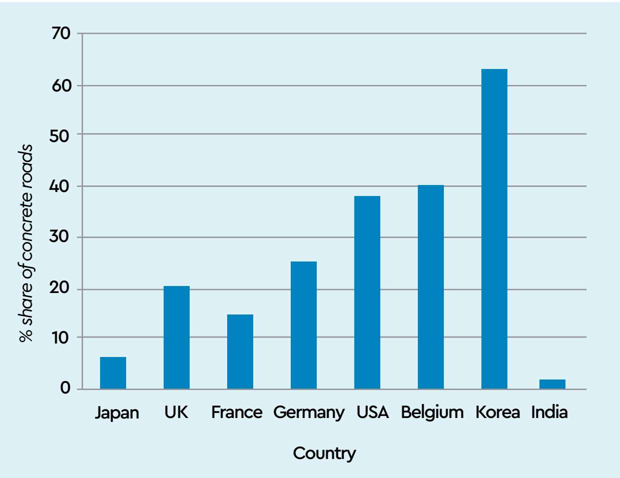
Since 2014, the speed of the construction of concrete roads for National Highways, expressways, in urban areas, and even at the village level has significantly increased due to the policy adopted by the Government of India [28]. Rough estimates suggest that approximately 2 percent of the total road length in our country is made of cement concrete. Figure 3 presents a comparative share of concrete pavement in the total motorable roads in India with respect to some more developed countries across the world. This suggests the trends of the future [29].

The cement industry has also taken up sustainability in its core production operation. The GHG emission control by clinker substitution, and the use of alternate fuel and raw materials have positively impacted the environment. The Global Cement & Concrete Association (GCCA) is positioning concrete as a sustainable material of choice for the housing, infrastructure development, including roads.

In the coming years, there will be a greater number of autonomous vehicle (partially or fully "self-driving"). Such vehicles will be able to 'read' the road with the help of pavement markings and communication with the infrastructure itself, and other vehicles. This means that durable, reliable road surfaces will be essential. This can be better facilitated by concrete roads.

The main challenge for concrete roads is the initial cost. However, the true value of the concrete road, over the entire life, is much higher than for bituminous roads. Better road infrastructure is essential for achieving progress in developing countries like India, and the use of materials with low environmental impact will not only result in a smaller carbon footprint but also represent a giant step towards a sustainable future.

Figure 3: Share of concrete roads in total motorable roads



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About GCCA India

Global Cement & Concrete Association (GCCA) India launched in July 2019 to work with the Indian cement & concrete sector on Climate Change, Circular Economy, Health & Safety, SDGs, and Advocacy. It currently has 13 member companies, aggregating more than 65% of India's cement production capacity.

The GCCA exists to drive advances in sustainable construction to demonstrate industrial-sustainable leadership in cement and concrete manufacturing. It is working hard to enhance the cement and concrete industry's contribution to many important global, social and developmental challenges.

Sustainable development of the cement & concrete industry is at the very core of the GCCA's work and has five pillars: health & safety, climate change & energy, social responsibility, environment & nature, and circular economy.

The GCCA gathers and publishes data on the industry's sustainability commitments, guidelines, and initiating research. The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete is the collective commitment of the world's leading cement and concrete companies to fully contribute to building the sustainable world of tomorrow. More information about 2050 roadmap and GCCA is available at https://gccassociation.org/.

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