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A Review on Rigid Pavement by Using Alternative Material

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Abstract: A considerable number of concrete pavements already exists on roads across the globe. Additionally, although asphalt pavements are now more prevalent, concrete pavements offer several unique uses. In addition, asphalt is a resource that is being used up at a quick pace, which might indicate that concrete will be the dominant material in the future. Yet, there are a few downsides to using concrete pavements, such as the high cost of construction, limited tensile strength, and substantial contribution to global carbon-di-oxide emissions. This research intends to remedy these shortcomings by surveying the most popular substitutes for cement and aggregates in concrete. We look at the possibility of using substitutes such fly ash, recycled concrete aggregate, coal ash, nano-silica, and silica fume. Plus, we go over what happens when you mix fibers into concrete pavements, whether in the form of fiber-reinforced concrete or engineered cementitious composite. Researchers and pavement engineers may also use this evaluation to determine the best material combination for improved mechanical qualities compared to regular concrete. While there has been a recent push by the government to find new uses for solid waste in an effort to lessen its negative effects on the environment, there has been very little effort along these lines in the Indian setting. Heavy traffic may be safely accommodated on rigid pavements, which are usually constructed of concrete due to their long lifespan and exceptional strength. While further research may be necessary to address the workability problem, this study provides a summary of global studies that have used several alternative materials to partially replace aggregates and cement.

Keywords: Rigid pavement, IRC, WFS, OPC

I. INTRODUCTION

For several reasons, roads are the preferred mode of transportation for both people and commodities. This is due to the fact that roads provide access to all doors. Concrete, sometimes known as stiff pavements, asphalt, or flexible pavements, and composite pavements are the three main categories of pavements according to the materials used to make them. Typically, Portland cement concrete (PCC) is used to make concrete pavements, hot mix asphalt (HMA) is used to make asphalt pavements, and a composite pavement combines the two materials. The high price and complex analysis required to build using composite pavements make them an uncommon building material [1]. Roughly 83% of all U.S. paved roadways are flexible pavements [2]. Table HM-12 in Highway Statistics 2017 issued by the US FHWA for the year 2017 indicates that the public concrete pavement length in the US is 57,744 miles, which is quite a bit. Table 3 of the

Road Statistics Annual Report (2017) [3] states that the length of concrete pavement in Japan is 34,593 kilometers. In addition, the share of concrete-paved main highways is rising rapidly and already accounts for about 20% in Switzerland, Belgium, and Germany [4]. There are 600 lane-kilometers of continuously reinforced concrete pavement in France, a country that has long used concrete pavements [5]. Although Sweden currently lacks a significant number of concrete roads due to conservatism, the country's experience with them has been positive. Even though concrete roads are more expensive to build than asphalt ones, the Indian Ministry of Road Transport and Highways (MoRTH) has decided to use them in all future national highways [6]. The world's population has exploded in the last few decades, leading to a marked uptick in urbanization on every continent. India, well-known as one of the world's developing nations, has seen massive shifts in the realm of infrastructure development, necessitating the demolition of obsolete structures and the construction of new ones to meet rising demand. Building new infrastructure has met the demands of existing scientific and economic institutions, such as universities, hospitals, stone modeling and smoothing units, craft industries, etc., all of which generate large quantities of solid waste, some of which is harmful to the environment.

Table 1. Typical Composition of Demolition Waste in Indian context

Sr. No.	Components	Percentage
1	Concrete	40%
2	Ceramics	30%
3	Wood	10%
4	Plastics	5%
5	Metal	5%.
6	Others	10%

Therefore, those in positions of authority, as well as researchers, engineers, and anyone interested in developing pavements utilizing new, perhaps locally accessible materials, may find it useful to conduct a state-of-the-art review on the use of alternative materials in concrete pavements. So far as the writers are aware, there is a dearth of reviews dealing with this subject. A number of waste elements have been investigated for potential use in concrete pavements; they include dust from cement kilns, recycled asphalt shingles, debris from construction and demolition, and broken bricks that have been recycled (Bakash et al., 2008). Variations in the mix's compressive and splitting tensile strengths, two measures of its durability, were the basis for this. Concrete pavements made from fly ash and plastic trash were the subject of a literature study by Yadav and Srivastava [9]. This research intends to add to the existing literature on the topic of alternative materials used in concrete pavements by drawing from a wider variety of sources. This is an attempt to provide a concise overview of recent research on the subject. Be advised that these alternative materials are only addressed in this article in relation to the wearing course of concrete pavements. The present review paper does not intend to go into the many other materials that have been suggested in the literature as potential base or subbase layer alternatives. This section will go over the mechanical qualities that should be present in a concrete pavement's wearing course, possible alternatives to cement and aggregates, the impact of including fibers in concrete pavements, and the potential areas for further research.

1.2 RIGID PAVEMENT

The primary function of rigid pavement, as a kind of road or pavement, is to distribute loads via a solid layer of surface. Portland cement concrete, which is a typical material for this layer, is very strong and resilient. Rigid pavements use the strength of the concrete slab to disperse loads over a large area, as opposed to flexible pavements that rely on a layered design. In the long term, this characteristic reduces deformation and maintenance needs. For best performance and durability, especially under heavy traffic, stiff pavements are designed with joints that control cracking and allow for thermal expansion and contraction.

Figure 1: Rigid Pavement

1.3 Use of Alternative Materials in Rigid Pavement

The widespread usage of alternative building materials for low-cost rigid pavement is a direct result of their cheap running costs and ease of maintenance. It lessens the load on local resources, improves the quality of interior environments, and helps with energy efficiency. Traditional materials like bitumen and crushed aggregates are available, but the production process for these materials has a devastating effect on the environment. Consequently, several waste by-products and materials have been assessed for potential use and implemented in the field as the road industry's assessment continues to expand. The field has made use of a number of recycled products. However, more in-depth research has emerged from both laboratory experiments and outdoor observations. There is an extensive list that includes recycled asphalt pavement, plastic, shattered glass, fly ash, pond ash, oil shale sand, and mine debris. Field usage of these items will aid in the conservation of rare and valuable natural resources. The road sector will therefore be able to create a superior recycled material via industrial practice and education. Plastic trash, fly and bottom ash, oil sand, and marble dust are the most widely used recycling materials nowadays.

1.4 Development of alternative materials

Researchers are looking for appropriate substitute materials when the supply of high-quality aggregates decreases and the cost of extracting them rises. For the purpose of evaluating nonconventional materials, standard test and specification procedures are inapplicable.

- When compared to more traditional materials, there may be significant differences in particle size, grading, and chemical composition.
- New, acceptable standards need to be established, and other materials are being considered for usage.
- On the other hand, the noteworthy performance-based test allows for the testing and comparison of both traditional and novel materials on the same apparatus.

2. Alternative materials to replace cement

One of the main ingredients of regular concrete is cement. Swapping out the cement in concrete for another substance is one approach to add non-traditional elements to the mix. By using materials that would otherwise be discarded, replacing cement may reduce land pressure, lower building costs, and significantly reduce greenhouse gas emissions. What follows is a discussion of some of the possible alternatives to cement in concrete.

2.1. Fly ash

Power stations that use coal as an energy source produce fly ash as a waste product. The addition of fly ash to concrete pavements improves their strength, abrasion resistance, and ability to overcome moisture barriers, according to the results. Due to a process that changes the microstructure of the concrete, this effect is caused by the combination of fly ash and cement hydrates. Fly ash is a great sustainable energy saver when used properly. The reduced alkalinity of fly ash concrete, in comparison to regular concrete, may be one of the disadvantages of utilizing it. The passivation coating on the steel reinforcing bar might be disrupted by solutions with low alkalinity. Since reinforcements are seldom used in stiff pavements, it is nonetheless preferable to apply fly ash in lieu of cement. Using fly ash as a substitute in concrete raises serious concerns about the material's slow strength increase in the beginning stages of the mix. The use of fly ash in road construction would inevitably cause additional delays for traffic services [10]. Fly ash is beneficial when combined with EAF slag, according to the reviewed literature, but it does not have much of an impact when used alone. Putting away the environmental effect and financial advantages, fly ash is not very useful for pavements, despite its widespread use in concrete mixtures. Also, it's not consistent; when tested with various materials, it sometimes shows a rise in strength and other times a decrease. Be that as it may, such findings might be the product of inconsistently high-quality fly ash. Consequently, more care has to be taken to guarantee that only high-quality fly ash is used throughout the building process. To replace natural aggregates, Lam et al. [11] used electric arc furnace (EAF) slag and varied the fly ash concentration of their samples. After 91 days, it was shown that using fly ash instead of other materials may increase the compressive strength by around 4%. To meet the strength and durability standards for pavements, it was suggested to use 20% fly ash. Based on their further research, Nassar et al. [12] found that fly ash samples with 50% replacement had a lower compressive strength than 25% fly ash samples up to 28 days of age (~3% lower), while samples with 50% fly ash showed a greater compressive strength than 25% ones (~15% higher) after 90 days.

2.2. Coal ash

While coal is an essential energy source, it is not without its drawbacks. The combustion byproducts and leachates include a variety of harmful substances, the most prevalent of which are mercury and selenium [16]. Soil and groundwater are also harmed by acid mine drainage (AMD), which is created when these harmful substances react with air and reduce the pH level [17].

The researchers came up with the idea of using the coal mines' waste as building materials as a possible solution to this issue. Coal ash, which is produced by burning coal waste powder (CWP), contains both floating ash and the ash that falls to the bottom of the combustion chamber. According to the authors, CWP is comparable to class F fly ash in terms of its pozzolanic qualities [18]. The production of coal bottom ash is on the rise globally, and with it comes the inevitable problem of dumping. Approximately 20% of the world's coal bottom ash is produced by India's almost 105 million metric tons of coal ash annually [19]. Because of this, it may find usage in pavements, which often need for large amounts of concrete [20]. Adding coal ash to concrete essentially maintains the mix's mechanical qualities and durability, with the exception of a little increase in elastic modulus and a little decrease in compressive strength every now and again. A feature that stands out is how cost-effective it is. The lack of encouraging findings in enhancing mechanical qualities suggests that coal ash should not be used in concrete pavement mixtures, which is likely why few studies have attempted to do so. But if we can get thermal power plants to produce coal ash of more consistent quality, we can have better outcomes. Plus, it may definitely result in a substantial savings if coal ash is readily accessible in the area. It is important to make sure that the quality of coal ash is consistent.

2.3 Silica fume

The production of silicon metal and silicon alloys produces silica fume as a byproduct. Due to its extremely pozzolanic character, it is most often used in concrete as a cement substitute. With the exception of a few number of instances involving RCC pavements, when a decrease in flexural strength was seen, adding silica fume to pavement concrete mixtures usually leads to improved mechanical qualities. Crumb rubber, which is known to weaken concrete at high concentrations, may have been an addition in these mixtures, which would explain the decreased flexural strength [25]. Finding the ideal replacement amount of silica fume for pavement applications seems to be an area with room for exploration. Also, before using silica fume in hard pavements, a full life cycle cost study has to be done. There is a lack of research on important qualities such creep, drying shrinkage, and freeze-thaw endurance. Despite its relatively expensive cost, silica fume has been extensively employed in concrete pavements for many decades due to the substantial increase in mechanical characteristics and fine particle concentration. On top of that, by taking the place of cement, it may significantly lessen the environmental impact of concrete. When making their pervious concrete pavements, Mondal and Biligiri [26] experimented with various amounts of crumb rubber (CR) and silica fume (SF) to substitute cement. While these modifiers did increase compressive strength and abrasion resistance, they also decreased the mix's permeability, especially in situations with limited CR replacement. We still don't know how much CR and SF to replace optimally. Still, there's room for improvement in making greener pavements and cutting down on cement's carbon dioxide emissions with the use of SF. By substituting 3% to 12% silica fume for cement, the weaknesses of pervious concrete—poor strength and freeze-thaw resistance—were mitigated [27]. Raising the degree of silica fume replacement significantly enhanced the freeze-thaw durability, with a maximum increase of around 62% for 12% replacement. Both the compressive and flexural strengths rose from 22 to 25.5 MPa and 4.8 to 5.2 MPa, respectively, at a 12% replacement level. Like freeze-thaw durability, these two qualities also showed rising trends.

2.4 Nano-silica

Microspheres made of silicon dioxide with a diameter of just around 100 nm make up nano-silica, a fine powder [29]. It is utilized in much smaller quantities (~5% by weight of cement) and is not as often employed in concrete as silica fume. Even with as little as a 1-3% replacement in concrete pavements, a noticeable improvement in mechanical characteristics is often seen. But a lot more superplasticizer is needed to keep the same slump class of nano-silica concrete, therefore excessive amounts of nano-silica are avoided [29].

2.5 Ground-granulated blast furnace slag

A byproduct of the steelmaking process is ground-granulated blast furnace slag, or GGBS. Compounds like calcium oxide and silicon dioxide make it up [32]. The drying shrinkage and the freeze-thaw resistance are both enhanced by the use of GGBS. At certain percentages of GGBS substitution, however, compressive, flexural, and cracking tensile strengths do sometimes improve. Take a 40% replacement as an example; it consistently produces better results, particularly after a year of curing. One obvious advantage of GGBS is the money it saves. Concrete containing GGBS has seen extensive application, similar to that of fly ash. Although its use in concrete pavements is restricted, it is not without its uses. This can be due to the fact that GGBS can sometimes have a detrimental effect on the mechanical characteristics of concrete that are important for pavements. Therefore, it is important to study how much GGBS to replace in concrete in order to enhance its mechanical qualities. To determine how changing the GGBS percentage affected the water permeability and freeze-thaw resistance of RCC pavements, Aghaeipour and Madhkhan [33] conducted an assessment.

Table2. Benefits and drawbacks of using ground-granulated blast furnace slag in rigid pavements

Cement substituent	Pavement type	Additional substituents	Benefits	Drawbacks
Ground-granulated blast furnace slag	Roller compacted concrete	Two different sizes of gravel	Cost decreases	Freeze-thaw resistance decreases and permeability decreases
		Crushed gravel/ limestone	Cost decreases, occasional improvements in compressive strength, flexural strength and splitting tensile strength	Drying shrinkage increases

3. DISCUSSION

Incorporating alternate materials into rigid pavements to achieve superior mechanical qualities was the main focus of this review paper. An indication of sustainability, this is unquestionably. Life cycle analysis (LCA) or life cycle cost analysis (LCCA) is a necessary component of overall sustainability assessments since it considers maintenance costs throughout the service life in addition to improvements in mechanical attributes. At first glance, a concrete pavement with a high waste percentage would seem like a sustainable option. Nevertheless, it's possible that the pavement may need regular repairs and maintenance as it wears down. In short, it is not a sustainable pavement in the broadest sense. The authors are unaware of many efforts to conduct a thorough LCA/LCCA of concrete pavements using alternative materials. However, there are a handful of studies that have looked at life cycle assessment in conjunction with using waste as a partial cement replacement in concrete [46]. In addition, there are difficulties in completing an exhaustive LCA/LCCA. The need to perform accelerated testing in order to forecast the pavement's durability is one example of a difficulty that could arise while trying to precisely replicate the pavement design life. A further difficulty that might arise is accurately estimating the total traffic throughout the pavement's design life, which is a crucial component of the LCA/LCCA. These are a few of promising avenues for further study. Despite the difficulties with cement and aggregates indicated in this article, the information gathered from the current research may help choose the optimal mix of locally accessible materials for concrete. Another consideration when deciding on an alternate material is the road's functional class, which might be arterial, collector, or local. Using cheap, low-performance materials in the construction of a local road, for instance, may not be a big deal. Nevertheless, high-performance is crucial for arterial highways.

4. COCLUSION

This article looked at the potential for Rigid pavements to use different materials. We were able to do this by compiling the pros and cons that various academics found while investigating the use of alternative materials in concrete pavements. Based on the literature study, this work mainly addresses the influence on mechanical characteristics. These are the main takeaways from the research: According to the studies that were evaluated, stiff pavements that are exposed to reduced loads may be made using recycled concrete aggregates. There are a few downsides to using RCA, such as lower workability when combined with fibers, but overall, silica fume and nano-silica greatly increase the mechanical characteristics of the concrete, making it an efficient choice for rigid pavement roads that need compressive strength less than 30kN/mm2. The only real advantages of using ground-granulated blast furnace slag as a cement substitute are the obvious savings in money and the rare enhancements to properties such splitting tensile strength, flexural strength, and compressive strength. The compressive and flexural strengths were found to decrease when recycled concrete aggregate was combined with almost all of the other materials tested. Aside from the obvious savings, there aren't many advantages, either.

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