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Comparative analysis of self-healing techniques for pavements

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Abstract - *In the realm of bituminous materials research, self-healing has become a hot topic. Interpenetration and bonding describe the healing mechanism, indicating that the cracking interface will vanish as a function of the time the cracking surfaces are brought into touch. The goal is to construct the pavement in such a way that the fractures mend themselves. Exhaustion and healing have been shown to be persistent issues throughout the life of a pavement. Deterioration of the road has a significant impact on its serviceability, riding quality, and safety. The flexible pavements experience major cracks and potholes due to heavy loads. The minor cracks are not repairable due to very little crack width and there may be under-surface cracks. In this research paper the heling techniques are analyzed and a comparative study is done. The healing techniques used are induction heating, nano-technology, micro-capsules, direct application of bacteria. In induction method, external temperature is provided for melting of asphalt and filling the cracks. In nanotechnology method, nanomaterials are used for self- healing process, whereas in microcapsules method, micro capsules are embedded in the mix, and these capsules break when cracks appear, and heal the fracture. The direct application of bacterial-based self-healing technology is an effective method for healing the cracks in deteriorated pavement. This technique will make the street self-healed and increase its lifespan and serviceability.*

Key Words: **Self-healing techniques, induction heating, nanomaterials, micro-capsules, bacteria, Bacillus Subtilis.**

1. INTRODUCTION

Construction industry plays a significant role by providing various structural materials that are used in various types of infrastructures [1], [2]. However, the major issue prevailing in construction industry is use of sustainable construction practices [3]. The ever-increasing high maintenance costs of various constructed infrastructures is the concern worldwide [4]. Self-healing has emerged as a hot issue in the field of bituminous materials research [5]. The healing mechanism is defined by interpenetration and bonding, which shows that the cracking interface will vanish as a function of the time and the cracking surfaces are brought into contact [6]. Exhaustion and healing have been demonstrated to be ongoing difficulties throughout a pavement's service life. Large cracks and potholes can be found in the pavement and other structural elements [7], [8]. Major fractures can be repaired, but smaller cracks are irreparable due to their modest crack width and location beneath the surface [9].

Overloading, seepage, inadequate road surface drainage, lack of suitable design, bad weather conditions, and a variety of other factors can cause cracks [10]. Because of the heavy loads, the flexible asphalts face major fractures and potholes. There is a fantastic approach for repairing potholes, and in any event, because of the heaps, there may be little breaches in the asphalt that cannot be repaired, resulting in major fissures in the pavement [11]. Minor breaks, in any case, are unrepairable due to the small break breadth and the possibility of under-surface breaks [12]. Fixing these breaks is extremely difficult because they aren't visible on the surface. In this approach, mending is out of the question. As a result, there are various ways for repairing asphalt damages without the assistance of others [13].

The first site trial of self-healing concrete at a large scale was done in UK. It is first time that self-healing concrete with micro-capsules has been successfully scaled up and implemented on-site. For comparison, self-healing concrete was made with the help of Na_2SiO_3 (waterglass) that were encapsulated at micro size was made on the site in holding wall panel alongside a control panel. After 35 days of cure, the walls were mechanically cracked, and then it was again loaded and observed for self-healing for 6 months for supervising permeability, fracture deepness, and microscopic fracture wideness values.

Even though the inclusion of 8 percent microcapsules by cement volume reduced mechanical strength marginally, the microcapsule wall demonstrated enhanced crack width and depth reduction, and permeability recovery, demonstrating the real-time viability of healing based on microcapsule. Van Tittelboom and De Belie investigated number of ways, some of which try to improve the genuine process of automatic fracture healing, whereas others aim to change concrete by inserting capsules with appropriate healing agents, allowing fractures to mend entirely on their own when they develop [14]. The sorts of therapeutic agents and capsules utilised are given special consideration. Furthermore, the various techniques have been assessed based on the trigger mechanism employed, with special focus devoted to the properties regained as a result of self-healing.

Yoo et al. have reviewed that the potential of asphalt concrete to self-heal was investigated using induction heating and quantified by differentiating the flexural strengths of untainted and recovered samples [15]. Adding carbon nanomaterials, such as nanotubes made of carbon (CNTs) and nanofibers of graphite (GNFs), proved more successful than adding macro-CFs in enhancing Marshall stability, indirect tensile strength, and dynamic stability, as well as lowering porosity. This strategy, however, is not applicable everywhere. Xue et al. have studied that PU-based polymer is the most promising self-healing agent known, with excellent flexibility and a comparatively quicker curing time, as well as a self-healing process that does not require water [16]. Stress concentration near the contact surface, separation of a solid self-healing agent, insufficient blending, and early reaction all require further adjustments [1].

Wiktor and Jonkers have reviewed that on crack-healing measurement in a new bacteria-based self-healing concrete. A new bio-chemical self-healing agent has the potential to improve the sustainability of concrete structures in humid situations [17]. Vijay et al. have reviewed on self-healing concrete which is prepared with the help of bacteria. The encapsulation method will produce superior success than direct application, revealing that bacteria can enhance the compressive strength and the durability of the concrete [18]. Mansoori et al. have reviewed that, at 20oC, fractured asphalt mixtures with capsules restored 52.9 percent of their earliest strength, compared to 14.0 percent for cracked asphalt mixtures without capsules. Asphalt self-healing capsules may be used securely on the road instead of amending its quality. The rigidity of capsules containing asphalt was slightly lower, which may be readily remedied in the future by reducing the capsule size [19].

Reddy et al. Stated that the involvement of bacteria into concrete may cause it to self-heal, lowering the structure's maintenance costs. The capability of concrete to self-heal can extend life of constructions [20]. Mullem et al. conducted a large-scale analysis in Belgium with the help of Self-Healing Concrete. A healing agent based on bacteria was added to concrete mix along with the other components. From the test done in lab it was observed that the cracks at the bottom and wet and dry cycles of the crack healing were visible closely [21]. On addition to that, the sealing efficiency of cracked sample which were soaked in water for 27 weeks, water permeability was measured from the measuring devices, that was found to be at least equal to 90%, having the efficiency of at least 98.5% for the biggest part of the sample.

Kimar and Kumar stated that rejuvenation, induction heating, and Nano materials are all healing strategies for flexible pavements. Self-healing pavements help to reduce maintenance costs while also extending the life of the surface [22]. Nanomaterials such as Nano rubber, Nano clay, and Nano silica can be used to improve the healing qualities of bitumen. When a crack emerges, the tiny capsules are added to the bituminous mix, and the resin is ejected. Steel fibres of various percentages and lengths have been used in pavements to heat the bitumen when fractures form. These are the many materials to be used, and there is still time to figure out the most efficient method for creating self-healing pavements [23]. Blaiszik et al. studied about Self-Healing Polymers and Composites. Healing systems based on capsules, vascular based and intrinsic healing polymers are three conceptual ways for self-healing that have been demonstrated [24].

Self-healing can be autogenous, meaning it proceeds its process of self -healing without any human interference, by utilizing external energy [25]. Despite the fact that capsule-based techniques are straightforward to integrate into many systems of polymer, this method is not used commonly. Vascular approaches have a lot of promise for mending large volumes of injuries across a variety of harm scenarios, but they're tough to integrate into existing material systems. Intrinsic healing treatments are lovely, but they're only good for little injuries because they require direct material contact to restore. Self-healing polymers show a better path to risk free, time- honoured, defect-surviving systems and constituents in, transportation. This work has been carried out on self-healing of pavements using bacteria.

2. MATERIALS AND METHOD

2.1 AGGREGATE

There are two categories of aggregates. Coarse aggregates and fine aggregates are the two kinds of aggregates. Coarse aggregates are those that pass through a sieve with a size of up to 4.75 mm. Fine aggregates and stone crusher dusts were obtained from a nearby crusher, with fractions passing 4.75 mm retained on an IS sieve of 0.075 mm. The specific gravity of which was discovered to be 2.78. Filler is aggregate that passes through a 0.075 mm IS sieve.

2.2 BITUMEN

Bitumen is a tar-like combination of hydrocarbons generated naturally or by distillation from petroleum and used for road paving and roofing. Bitumen is a petroleum liquid or semi-solid that is black and exceedingly viscous. This project employed VG 30 viscosity grade bitumen as a binder in the mix formulation.

2.3 BACTERIA

The bacteria selected for this process is Bacillus Subtllis.

3. RESULT AND DISCUSSION

Looking forward towards the pavement that heal itself, the techniques that help in making self-healing pavements are:

1. Induction Heating
2. By using Nano-Materials
3. By using Micro-Capsules
4. By direct application of bacteria

3.1 INDUCTION HEATING

The asphalt mix is combined with these fibres, and the pavement is placed down. When fractures occur, the facet of the pavement is heated using induction heating, which allows the steel fibres to conduct heat and results the bitumen to glide and jam up the minor fissures. The exchanging current via the spiral triggers a changing electromagnetic field, which initiates the induction heating process [15]. When the conductive asphalt specimen is placed under the coil, the electromagnetic field causes currents to flow down the conductive loops that have emerged from the steel fibres. This strategy was also used in the Netherlands, where test tracks were laid and the performance was satisfactory, and many new highways were built using this method. Steel fibres, Steel wool, Graphite, Carbon are the fibres that will be used in this process. Different writers tested with the fibres for percentages of two part, four parts, six parts, and eight parts.

The heating temperature of asphalt for healing is very high nearly about 85oC-100oC. External heat is to be provided. There is no way to keep records of the cracks formed in the pavement. Induction heating types of equipment are complex, and adaptability to the poor, difficult to guarantee the quality of work in non-uniform areas. The demerits in this method are that the heating temperature of asphalt for healing is very high nearly about 85oC-100oC. External heat is to be provided. There is no way to keep records of the cracks formed in the pavement. Induction heating types of equipment are complex, and adaptability to the poor, difficult to guarantee the quality of work in non-uniform areas.

The cost of inputs is comparatively high.

3.2 NANO MATERIALS

Nanotechnology entails research and development at the atomic, molecular, and macromolecular levels, with length scales ranging from 1 to 100 nano-meters, in order to provide a fundamental understanding of phenomena and materials at the nanoscale, as well as the creation and use of structures, devices, and systems with novel properties and functions due to their small and/or intermediate size [26]. Pavement mending involves the use of nanomaterials such as nano silica, nano clay, nano rubber, Nano SiO_2, TiO_2, and others. Researchers have mostly worked with nano silica, nano rubber, and nano clay [27]. Bitumen was combined with nano silica in various ratios. Nano silica particles may penetrate crevices and fill gaps due to their high surface energy. Nano silica will aid in the healing of cracks [28].

The mechanical parameters of the bitumen are improved by adding Nano silica, as is the bitumen's strength. The nano silica percentages used range from 2 to 10%. Nano silica reformed concrete has a higher rutting resistance and anti-stripping property than traditional bituminous concrete. Nano clay and nano rubber will also be employed to improve the bituminous concrete's healing qualities [29]. Nano clay modified bitumen can improve mechanical qualities such as indirect tensile strength, creep resistance, and fatigue resistance. When compared to ordinary bituminous concrete, the elasticity of nano clay modified bituminous concrete is higher, as are the rheological parameters.

Various Atomic Force Microscopy (AFM) techniques (i.e. tapping mode imaging, force spectroscopy, and nano-indentation) as well as X-ray diffraction (XRD) experiments were conducted on asphalt binders modified with different contents of a nano-clay material to characterise the nano and micro-structure and mechanical behaviour of asphalt clay nano-composites. The addition of nano-clay modifiers to bitumen increased the asphalt's stiffness, which improved rutting resistance.

Nanotechnology will benefit society in two ways: by improving the cost, durability, and efficiency of existing items and processes, and by generating wholly new products [30]. In particular, the characteristics of asphalt and asphalt mixtures. Nanotechnology has the various well-known benefits. It improves the storage stability of polymer modified asphalt and improve UV ageing resistance Reduce the susceptibility to moisture under water, snow, and deicers. Improve the characteristics of low-temperature asphalt mixes [31]. Asphalt pavements should be made more durable. Conserve energy and money so that maintenance requirements are reduced. While there are many possible concepts and uses for nanotechnology and pavement engineering, it's also vital to be realistic and recognise and accept the field's current limitations and constraints. Environmental, health, and safety considerations, as well as issues with scaling nano-effects and prices, are among the concerns and obstacles [32].

Because pavements are built in the natural environment, all materials (including nanomaterials) used in their construction and maintenance must be compatible with the natural environment, and their environmental impact must be limited. As part of the examination of nanotechnology solutions in engineering, the technical and cost-effectiveness of various technologies should be assessed. The problem with this method is that it is hazardous to human health and has the potential for exposure and determine the health risk of nanoparticles [33]. The majority of nanotechnology equipment and materials cost a lot of money right now. This is due in part to the technology's novelty, but also to the equipment's complexity [34].

3.3 MICRO-CAPSULES

The capsules are mixed with the binder and filler, which facilitates in the treatment of cracks after they have formed, as the capsules' energy may burst and release the resin or binder, resulting in crack repair [35]. The primary goal of a rejuvenator is to change the properties of the asphalt mix, lowering the stiffness of the oxidised asphalt binder and fluxing the binder, so extending the life of the pavement. These microcapsule shells are sufficiently reliable both thermally and mechanically. Reclaimed paxole1009, cycle paves, and ACF iterlene1000 are a few commercially convenient rejuvenating agents to endure the asphalt producing activity [36]. The oily rejuvenator is the most successful microcapsule shell to date, consisting of a prepolymer of melamine-formaldehyde reformed by methanol and the resultant product. The advantageous microcapsule route for asphalt self-healing enables the rejuvenation of old binder. In an asphalt mix, the optimal content of microcapsules in the bitumen should not exceed 30% of the total volume of the bitumen [19].

This is an experimental technique that will be extremely useful once it is implemented. Modulating the core/shell ratio, on the other hand, has an impact on and control over the capsule's size. The microcapsule diameter should be 25m; lesser diameters, such as 10m or smaller, do not contain enough rejuvenator and are thus unsuitable for self-healing. Also, capsules larger than 30m are not employed since they facilitate the interface separation between microcapsule sand binders, resulting in the appearance of cracks [37]. As a result, the capsule size should be between 10 and 30 m, and the volume should be between 10 and 30%. The main problem of using the pavement mixture mixed with microcapsules is that these capsule act as voids or hollow spaces which reduce the strength of the pavement.

3.4 DIRECT APPLICATION OF BACTERIA

The bacteria which is rich in calcium nutrient is added up in the concrete when the mixture is made. When the cracks occur in concrete calcium carbonate is precipitated from bacteria which seals the crack. The addition of bacteria in the concrete will form a pervious layer when concrete gets fractured. The bacteria which can work in alkaline environment is chosen because concrete is highly alkaline in nature [6]. The calcium carbonate precipitate formed by embedding bacteria in concrete not only fills the cracks but also binds the other components of the mixture as sand and aggregate. Thus, the calcite precipitation enhances the durability of concrete. By direct application of healing agent in concrete in LWA i.e., light weight aggregate and GNP i.e., graphite nano platelets, it is found that GNP acts as the better exporter amalgam for bacteria and gives more promising results in healing of cracks.

- Bacillus Subtilis bacteria + lightweight aggregate/graphite nanoplatelets = strength of the concrete is increased.

- Bacillus Aerius bacteria + rice husk ash concrete = the durability of concrete is increased.

- Bacillus Megaterium bacteria when used in concrete increases compressive strength by 24%.

- Sporoscarcina Pasteurii bacteria+ fly ash concrete = enhance strength and durability of fly ash concrete

- Sporoscarcina Pasteurii bacteria + silica fume concrete= enhance strength and durability of silica fume concrete.

The analysis of the material used for the pavement is very essential factor because it affects cost efficiency, durability and safety of transportation system. This analysis helps to provide the information about the characteristics of the pavement to determine its quality. Table 1-3 show the results of the studies carried out that have been further plotted in Figure 1.

Sl. No.	Description of Test	Specification As Per MORTH Table-500-18	Test Method	Test Result
1	Impact Value Test	Max - 24%	IS - 2386 (Part 4)	17.66%
2	Flakiness & Elongation index	Max - 35%	IS - 2386 (Part 1)	9.3% & 12.5%
3	Specific Gravity Test	1.5 - 3	IS - 2386 (Part 3)	2.64
4	Water Absorption Test	Max - 2%	IS - 2386 (Part 3)	0.195 %

Table 1. Test on aggregate

Sl. No.	Description of Test	Unit	Result obtained for Bitumen
1	Penetration Test	mm	54.95
2	Softening Point Test	ºC	47.5
3	Specific Gravity Test	-	1.006

Table 2. Test on bitumen

Bacteria (%)	Maximum Stability(KN)	Flow (mm)	Air voids (%)	Voids filled with bitumen (%)	Optimum binder content (%)
25	19.45	2.84	4.84	72.53	5.56
50	23.69	2.84	4.72	73.13	5.62
75	17.52	3.45	4.34	73.32	5.70

Table 3. Marshal Stability

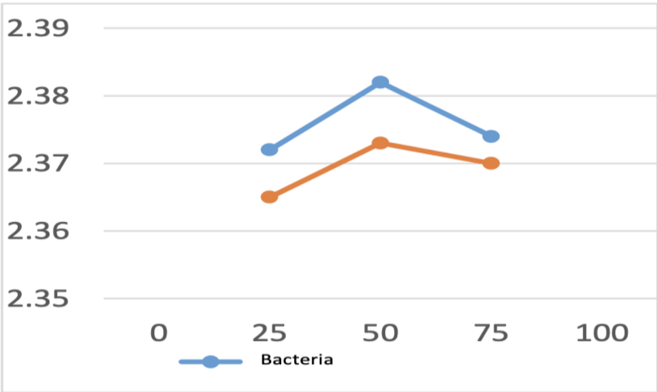

Figure 1. Comparison of bulk density with and without bacteria

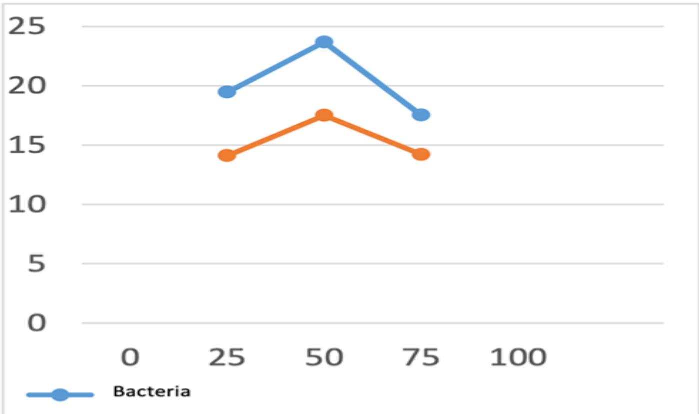

Figure 2. Comparison of Marshall Stability with and without bacteria

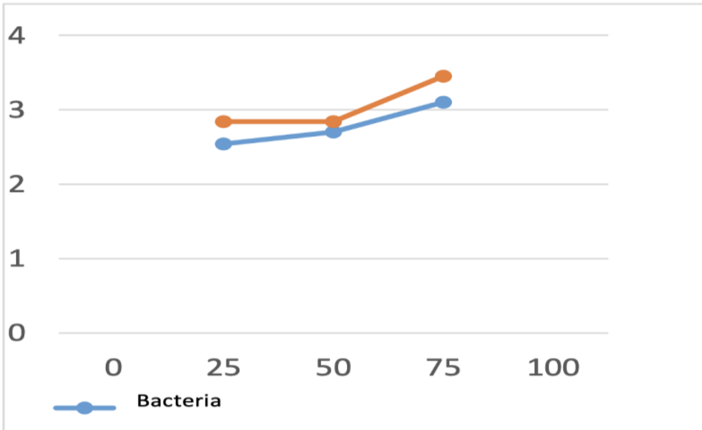

Figure 3. Comparison of Marshall Flow with and without bacteria

The graphs are plotted for 25%, 50%, 75% replacement of aggregates with bacteria and compared with values of conventional mix. By comparing the above graphs, it is found that 50% bacteria give the best result, because when compared 25% and 75%, 50% bacteria used has higher stability than the other two slags. So it is concluded that 50% bacteria is better for self-healing pavement and it is found that bacteria have lower flow value, it's because the bacteria has porous and dense characteristics.

4. CONCLUSION

This research paper is focused on the various self-healing techniques for the construction of pavement. There have been a variety of techniques, but this research paper focuses on the most efficient technique for making the pavement self-heal. These methods are induction heating, nano-technology i.e., using nanomaterials, microcapsule, and direct application of bacteria.

Induction heating method requires external heat for self-healing as it heals at high temperature which needs induction heaters. The cost input method in this method is comparatively high. Pavement modified with bitumen do not self-heal properly under low temperature and the fatigue resistance lowers in modified bitumen. The problem with nanomaterials is that it is hazardous to human health and has the potential for exposure and determine the health risk. The majority of nanotechnology equipment and materials cost a lot of money right now.

The addition of microcapsules to the pavement mix reduces the strength of the pavement as microcapsules act as the void in the mix. Adding bacteria to the concrete mix improves its compressive strength, durability, and stability. According to the tests performed by various researchers it is found that the replacement of half the amount of aggregate with bacteria gives higher stability to the pavement. After a comparative study of all the methods, it is found that the direct application of the bacteria method is found to be the most promising method. The suggested technique used in the above-explained data clarifies the roadmap for the researchers and enables them to conduct further research in designing self-healing pavements.

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