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Self-Healing Techniques for Sustainable Pavements - A Review

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Abstract

This paper summarizes the various problems that occur in flexible pavements also emphasize the necessity of adopting self-healing techniques in order to have efficient self-healing pavements. The healing techniques for flexible pavements are rejuvenation, induction heating and Nano materials. The induction heating is in existence and pavements are laid in Netherlands. The self-healing pavements fetch in scaling down the maintenance cost as well as improve the pavements' lifespan. Several research works are done on these self-healing techniques. And a lot is going on to find out efficient one. The scope exists for Nano materials and micro capsules (rejuvenation). Furthermore, the healing properties of the bitumen can be enhanced with the use of Nano materials like Nano rubber, Nano clay and Nano silica. The micro capsules are introduced to bituminous mix and resin is expelled out when crack appears. The steel fibres with different percentages and in different lengths are used in pavements and are used to heat the bitumen when the cracks are appeared. These are the different materials to be using and the scope exists to find out the efficient technique for making the self-healing pavements.

1. Introduction

The flexible pavements experience major cracks and pot holes due to heavy loads. There are lot of repairing techniques for repairing the pot holes and major cracks. But due to the loads, there may be also minor cracks in the pavement, which will result in major cracks and pot holes after the repairing. But the minor cracks are not repairable due to very less crack width and there may be under surface cracks. The repairing of these cracks is very difficult as they can't appear on surface. So, repairing is not possible. Then we have to make the pavement in the way that heals the cracks by itself. There are healing techniques which will heal the cracks by itself.

The techniques are:

- Induction heating
- By using nano materials
- By using micro capsules

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These self-healing techniques will help in healing the micro cracks and reduce the repairing and maintenance costs. The Netherlands had used the induction heating technique for Dutch highway and the results are good. And also, they constructed another 12 highways with this technique. The nano particles like nano silica, nano clay, nano rubber give promising results when mixed with bitumen to heal the micro cracks. This technique is in research state and will be a efficient one, once it gets into practice. The micro capsules with rejuvenator will also heals the micro cracks with the resin within it when expelled.

2. Self-Healing Techniques

2.1. Nano Materials:

Various Nano material like nano silica, nano clay, Nano rubber, Nano SiO_2, TiO_2, etc., are used in healing of pavements (Su *et al.*, 2013). Mostly researchers have conducted experiments on nano silica, nano rubber and nano clay.

The nano silica was mixed with bitumen in different percentages. Due to the high surface energy, nano silica particles can make in to the spaces and will fill the gaps. The nano silica will help in healing the cracks. By adding the Nano silica, the mechanical properties are increased and the strength of the bitumen will also increases. The percentages of the nano silica used are varies from 2 to 10 percent. When compared to conventional bituminous concrete, the rutting resistance as well as anti-stripping property is high in Nano silica reformed concrete (Su *et al.*, 2013).

Nano clay and nano rubber will also be used to increase the healing properties of the bituminous concrete. Mechanical properties like indirect tensile strength, creep and fatigue resistance can be increased with Nano clay modified bitumen. The elasticity of the nano clay modified bituminous concrete is high compared to the conventional bituminous concrete. And also the rheological properties are also increased (Yang and Tighe, 2013).

2.2. Induction Heating:

These fibres are mixed with the asphalt mix and the pavement is laid down. With the appearance of cracks, the pavement's facet is heated using induction heating that enables the steel fibers to conduct heat and will make the bitumen flow and fill in the minor cracks. The proceeding of induction heating is instigated by triggering alternating electromagnetic field from the alternating current through the coil. The electromagnetic field actuates currents flowing down the conductive loops emerged from the steel fibers when the conductive asphalt specimen is placed under the coil (Su *et al.*, 2015).

The healing of asphalt concrete is noted for its temperature dependent phenomenon and in corresponding to that abundant evidence has been divulged by various researchers in support of the healing mechanisms (Liu *et al.*, 2010). This process was also in existence in Netherlands, test tracks were laid and the performance was good and many other highways are also constructed with using this technique.

The fibres that are to be used for this technique are

- Steel fibres
- Steel wool
- Graphite
- Carbon

The fibers used are experimented for percentages 2%, 4%, 6%, 8%, by different authors.

Figure 1. Fibres used in induction heating

2.3. Micro Capsules (Rejuvenation):

The capsules are mixed with the binder and filled with binder, which helps the cracks to get heal after its formation, as the energy that capsules may burst and release the resin or binder, resulting in crack healing. Altering the properties of the asphalt mix and thereby scaling down the stiffness of the oxidized asphalt binder plus to flux the binder; accordingly to enhance the pavement life is the paramount intention of rejuvenator. Reclamite paxole1009, cyclepave and ACF iterlene1000 are few commercially convenient rejuvenating agents

To endure the asphalt production activity, these micro capsule shells are adequately reliable both thermally as well as mechanically. Comprising of a prepolymer of melamine - formaldehyde reformed by methanol and the consequent product was the oily rejuvenator is the most flourishing micro capsule shell so far.

Enabling the rejuvenation of aged binder is the propitious microcapsule avenue for asphalt self-healing. In the confines of asphalt mix, the ideal content of microcapsules in the bitumen should not overreach 30% of the whole bitumen volume. This technique is in experimental process and this will be very useful once if it is implemented.

However modulating the core/shell ratio impacts and controls the size of the capsule. The micro capsule diameter should be 25μm; further like 10μm or smaller diameter do not incorporate adequate rejuvenator and hence not suitable for self-healing. Also capsules larger than 30μm are not used as they end up in the emergence of cracks by facilitating the interface separation between microcapsule sand binders. So, the size of the capsules should be in range of 10-30μm and the volume should be of 10-30%.

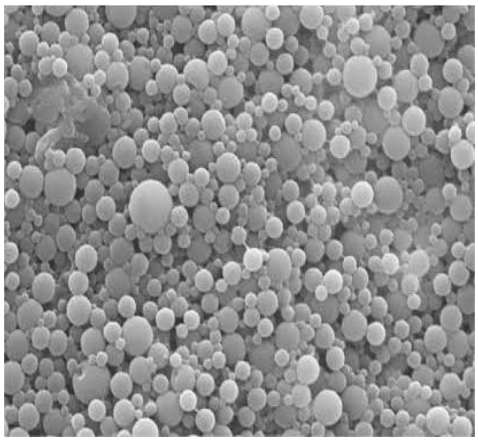

Figure 2. MicroCapsules

3. State of the Art

The various works are carried on self-healing pavements. The literature survey is carried out on investigating the self-healing roads. The observations are listed below.

3.1. Literature Review:

(Castro and Sánchez, 2006), succeeded in instigating an experimental fatigue test that embraces resting time. The prototype sustained a total of 1.1s of cyclic conditioning with bridled displacement at 20o C that incorporating 0.1s sinusoidal loading wave and another second as a rest period. Abundant tests were executed with and without the rest period to examine their sway on the fatigue life. The equivalent fatigue curves have been procured from the processed experimental outcome and they have been analyzed to reaffirm that they are unalike with the aid of discriminate anatomization. Pretty much five to ten times surge is identified in mixture of fatigue life ascribed to the mixture healing when turning up the rest period in the time of the tests. Comparatively inquiring the test results by wielding the statistical tools than visual evaluation, enables the researcher to draw inferences with scrupulous attention. It is also articulated that they were outstanding adjunct to the conventional regression audit.

(Williams *et al.*, 2007), describes that self-healing using carbon fibres has application in aerospace engineering. In order to yield slight degradation in flexural strength as well as ply disruption, they have flaunted the amalgamation of HGF confined in a CFRP laminate. All the more on the preponderance demanding interface of 0/45, a superlative embedment of HGF is accomplished with three HGF diameters (200 lm) stowed at fiber spacings. In the course of fiber creating procedure, the insertion of HGF by unmediated loop onto CFRP pre-peg is facilitated by the developed fiber tension. As the inceptive viscosity drop prior to gelation lubricates the resin and fiber maneuver about the sizeable HGF, additional enhancement is spotted during the cure. At a ply interface, in view of the equivalent dispensation of HGF it is implied that they do not concoct flawed sites subjected to these loading conditions owing to the fact that they do not seem to induce evident crack path deviation. Nevertheless, crack path deviation is engendered from eloquent turmoil with the undersized pack of HGF when integrated with resin rich areas.

(Qiu *et al.*, 2009), chronicles an initial step in asphalt mixtures by reforming their self-healing properties. He contemplated that the self-healing capability of bituminous binders could be enhanced thereby extended service life is feasible through the reversible ionic bonding, Nano particles as well as reversible hydrogen bonding from mimicking nature. Furthermore, the self-healing competence with ionomers, Nanoparticles and supra molecular rubbers in time of reformed bitumen will be the succeeding indagation.

(Liu *et al.*, 2010), the induction heating has been elucidated and has carried out different tests to check the healing percentages and concluded that, the electrical conductivity as well as particle loss resistance is strengthened with the inclusion of steel fiber to asphalt concrete. On top of that in case of porous asphalt concrete, small-scale diameter of long steel wool is more efficacious than larger diameter of short steel fibers. Maximal healing rate is obtained with the volume of fibers and also the activity of induction heating was facile with the induction energy in case of steel fibers embedded in porous asphalt concrete samples. In order to attain electrical conductivity, induction heating speed as well as good particle loss resistance, the ideal content of steel fibers is about 10% comprising of 10 % steel wool type 000 is further extended with induction heating in porous asphalt concrete.

(Phadke *et al.*, 2012), researched and reported the self-healing properties by the role of hydrogels. The study inferred that, A6ACA hydrogels are used as self-heating coating, can also been used for

plastics, for sealing acid leakages, mucoadhesive polymer, drug carrier and concoction of involute structures by exploiting their healing potentiality. When the stress is unfettered, the healed samples are competent to bolster substantial deformations and could recoup their size and shape. The findings suggest that the hydrogen bonding over the two hydrogel interfaces around in the amide and carboxylic functional groups might be medicated from the elastomeric properties of the A6ACA hydrogels on the edge of their versatile side chains.

(Frei *et al.*, 2013), explained about the self-repairing of the pavements and different methods that helps in healing the cracks and repair the roads. They have concluded that, self-healing techniques have a good scope to research, about the self-repairing techniques and it will help to reduce the maintenance cost of roads after construction and also repairing will be very low. The study includes the various failure types as accidental damage, fatigue, corrosion/degradation, design problem, also stated that, self-managing software and self-organizing software are used to assist and analyze the cracks and failures.

(Liu *et al.*, 2013), describes about the test methods, results of self-healing asphalt road and its behavior. With the induction heating, on account of the reinforcement of steel wool as well as enhancement in the healing capacity exceptionally tweaks the durability of porous asphalt roads. Wielding both cylinder as well as beam samples, the inherent healing of porous asphalt concrete fused with steel fiber is also analyzed. They concluded that induction heating hikes the healing competency of porous asphalt concrete and in addition to that ultimate healing rate for porous asphalt concrete is achieved at 85 degrees optimum induction heating temperature.

(Su *et al.*, 2013), well investigated the stability of rejuvenator encompassed with self-healing microcapsules. The various tests were carried to determine the micro capsule stability and durability in the self-healing pavements. The microcapsules can outlast the thermal effect of bitumen which was authenticated with their survival up to 2000C temperature. The shell material was formaldehyde. Concludes that, equipping with greater shell thickness by dint of modified resin and increased shell material promotes higher stiffness of elastic micro capsule.

(Fang *et al.*, 2013), given a detailed review on behavior of Nano materials in asphalt modifications. Materials like poly ethylene, ethylene vinyl acetate, 12rubber, as well as styrene butadiene have been identified to use in asphalt modifications. It was concluded that, the modified asphalt was efficacious with Nano materials as they tweak the properties of asphalt whilst the modification of Nano materials is a chemical reaction process on the base asphalt.

(Yang and Tighe, 2013), explored the advantages of asphalt blended with Nano materials. Augmented viscosity of asphalt binders besides enhancement in the rutting and fatigue resistance of asphalt mixtures is attainable with the inclusion of Nano clay in the asphalt. However, employing Nano clay boosts the aging defiance of asphalt mixes except one peculiar kind of montmorillonite, Nano-clay doesn't govern the stiffness and viscosity of asphalt binder. In the wake of nanoscale dispersion and inclusion of Nano-particles, polymer Nano composites authenticate as the most gripping materials. Further, the polymer reformed asphalts blended with Nano-particles revamp the storage stability.

(Taherkhani and Bayat, 2015), studied about enhancing the properties of asphalt by employing Nano materials. Varied materials like Nano-tubes, silica, Nano clay has been investigated. The viscosity of asphalt binders was increased as well as the rutting and fatigue resistance of asphalt mixtures was tweaked with the inclusion of Nano-clay in asphalt. Also the aging resistance of the asphalt mixes can be enhanced with the utilization of Nano clay. Furthermore, an opportune performance in cold regions accompanied by benefits is viable through engineered preference and optimization of Nano-materials in the asphalt.

(Tabaković and Schlangen, 2015), investigative studies were carried out on self-healing roads and given a detailed information on self-healing techniques that can repair the obtained cracks. Identified three major improvement aspects that can be considered that

- Cognizing damage as well as repair triggering elements
- Multiple self-healing processes evolution
- Evolution of self-healing evaluation procedures

(Su *et al.*, 2015), describes that approach of using the micro capsules with waste cooking oil. He concluded that microcapsules as rejuvenator for bitumen which could be disseminated unvaryingly in the bitumen was effectively encapsulated by WCO. The micro WCOs can pragmatically executed in bitumen without fracture prior to utilization due to their superior thermal stability as well as survival even in melting bitumen (180C). Forbye, the micro WCOs have immoderate modulus that is incumbent to resist the deformation which is reaffirmed from their mechanical properties. The emanated micro WCOs in bitumen from the maneuver morphologies of WCO, by review it is inferred that WCO as a rejuvenator can be deftly crept into the aged bitumen. Besides, there were trances to claw back the virgin properties of the rejuvenated bitumen at the site. For the aged bitumen, an unusual avenue is endowed and moreover an environmental and economical explication for the waste material is pioneered by the effective exertion of micro WCOs.

(Norambuena-Contreras and Concha, 2016), has given detailed information on healing of cracks through microwave heating technique. Experiments were carried out using different proportions of steel fibers (2%, 4%, 6%, and 8% of steel fiber by the volume of bitumen with length ranges from 2 mm to 8mm) in asphalt mixes to analyse the properties. Concludes that, the difficulty arising with the asphalt pavements can be minimized by incorporating self-healing technology (for example, use of Nano particles and microcapsules have future scope as the maintenance cost is less) in the design of asphalt pavements. Experimental results show that, properties (bulk density, particle loss resistance, electrical resistivity and conductivity) with higher contents of fibres in the asphalt mix do not contribute significantly to improve healing capacity and flexural strength of asphalt mix i.e., 2% of fibres by volume bitumen recommended, that results taking healing level over 80%. Concludes that, crack healing in asphalt mixture through microwave heating is possible.

(Micaelo *et al.*, 2016), details about the usage of capsules (rejuvenation) in the self-healing asphalt. A capsule composed by a calcium alginate core, where sunflower oil is entrapped and an external protective shell made of epoxy and cement were used for the experiments work. A very high strength which is required to withstand the high temperatures along with stresses in the course of asphalt mixing and compaction procedures is achieved from the external shell. These results show that, the encapsulation of rejuvenators in asphalt mixtures is feasible and can help in progressing the road pavement durability. These capsules have good content of rejuvenator and can be made with different size and strength characteristics. It is intended to continue investigating the incorporation of these capsules in asphalt, namely the effect of the size and strength characteristics in mastic behaviour modification.

(Mostafa, 2016), describes the behavior of the hot mix asphalt and taken the samples with 1, 3, 5, 7, 9 % of Nano silica and 0.01, 0.1, 0.5 and 1% of Nano carbon tubes and the results are 0.5% and 7% of Nano-carbon content decreases the penetration degree though mechanical commixing by 9.4% and 7.13% and through high shear commixing it is decreased by 9.8% and 8.1% respectively. Equally, a 0.5% of Nano-carbon content increases softening by 14.3% in both mechanical and high shear commixing,

while 7% Nano-silica increases softening by 9.52% and 11.9% through mechanical and high shear commixing. Moreover, a 0.5% of Nano-carbon and 7% of Nano-silica content increases viscosity by 10% and 8.33% through mechanical commixing and by 11.67% and 10% through high shear commixing respectively.

(Tabaković *et al.*, 2017), carried out research work on fibre optimisation in microcapsules. The main objective is to ascertain the maximal rejuvenator that can be encased without reflecting badly on the fiber thermal and mechanical properties nonetheless tweaking the healing efficiency of the system through optimizing a design of compartmented alginate fiber encapsulated rejuvenator. It is evident that, owing to high volume of compartments as well as solidity at varied temperatures whilst perpetuating abundant mechanical strength in the asphalt mixes followed a climb in the rejuvenator/alginate ratio achieving to 70:30.

(Amin and Esmail, 2017), describes the application of Nano silica to asphalt mixes, that results in highest HI blended with 3% of Nano silica by means of ultrasonic high shear mixer to the bitumen plus 6.5% bitumen also 4% limestone aggregate with air voids. The diffusion of Nano silica into the bitumen is clearly detectable from the captured SEM images of the reformed bitumen encapsulated in a successful mix of Nano silica and bitumen. Reporting to healing as well as healed micro cracks of HMA samples, they proclaimed that the bitumen mortar flow as the prominent mechanism promoting the self-healing of asphalt mixture from the captured vandalized SEM images. Inhibiting the augmentation of Nano silica content to 3% revamps the HI and furthermore accretion of content dwindles the HI. He deduced that due to high specific area subjected to extortionate Nano silica impedes the crack healing process by subsuming inordinate amount of binder, thickens the reformed bitumen as well retarding the mobility.

(Riara *et al.*, 2018), carried out research work on investigating the potential of aged and unaged AC-13 basalt asphalt mixtures by utilizing five healing agents on the subject of crack healing. The reclaimed critical load at fracture as a healing indicator was espoused abreast of cracking and healing of notched semi-circular asphalt mixtures. The rehealing performance being sensitive to drying rate of healing agents in addition to the high drying rate reduced rehealing performance. The diligent preference of healing agents yield the flair for healing cracks in asphalt pavements with high healing performance.

(Abo-Qudais and Suleiman, 2005), describes about the fatigue and cracks that are obtained in the asphalt and they conclude that evaluating the percent of extension in ultrasound pulse velocity besides the added fatigue life facilitate in assessing the crack healing. With the increase in the number of constant stress fatigue loading cycles, a consistent decrease was perceived in the UPV. Non-destructively without crushing the specimen, the UPV can be exercised to previse the crack healing. Prognosticating the extended fatigue life was much better than its proficiency to previse the fatigue life prior to healing can certainly be the propensity for UPV. Whilst vulnerable to the effects of aggregate gradation, rest period length, temperature and as well to healing.

4. Conclusion

Flexible pavements need maintenance periodically to reduce the damage. As the self-healing techniques helps to reduce the cost for maintenance and also increases the life of the pavement. Now, in practice there is only one technique is to be in usage i.e. induction heating. The use of Nano particles and micro capsules should be increase to reduce the maintenance cost with respect to the technique which is in practice. There is scope for research for these techniques and this will be very helpful for the future generations to make these pavements. Nano particles like Nano clay and rubber are using to heal the

cracks furthermore sufficient details were available that provide ammunition to the long-term effects of these substances in asphalt mix. There is a lot of requirement of these roads in the developing countries like India. By using these roads, the life period is also increasing which is very useful.

In this paper, the information about self-healing techniques and some of the authors who have done the work on self-healing roads are discussed and their conclusions are given. And there are lot of authors who have worked on this topic and there is scope for future research.

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