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A Review on Asphalt Pavements Crack Healing Methods (Induction of Healing & Microwave Heating Methods)

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Abstract— **The idea that bituminous pavement can self-heal offers a great chance of extending the pavement's lifespan. Another self-healing technique for asphaltic pavements is microwave heating/healing, which works similarly to induction healing but uses magnetic radiation to cure the asphalt mixture rather than electric field-induced induction healing processes. Electromagnetic (EM) waves can be absorbed by conducting fibers and transformed into thermal energy. This article compares and thoroughly studies the two types of heating/healing systems. Because the customary over-design of materials is no longer required, this method contributes to the conservation of material resources. Damage will be fixed right away, negating the need to rebuild and lay bituminous pavement.**

***Keywords*—Asphalt, Bituminous Pavement, Electromagnetic waves, Induction healing, Microwave heating, Self-healing.**

I. INTRODUCTION

For the majority of people, driving is their primary and preferred form of transportation, and India has one of the busiest road transportation networks in the world [1]. The world's second-largest road network is found in India behind Peoples Republic of China (PRC). According to data provided by the authorities, road transportation is the primary and preferred form of transportation for the majority of the people, and India's road transportation system is among the most commonly used in the world [1]. With 63.73 lakh kilometers of road network, India boasts the second largest road network in the world. With a 4.8% GDP share, road transport has grown to become a significant part of the Indian transportation industry [2]. Approximately Rs 970 billion would be allocated by the Union budget for the roads and highways sector, with a significant portion of the yearly road budget going toward road rehabilitation, repair, and upkeep [2, 3]. While most people agree that maintenance is necessary, it is not being done correctly. In order to provide safe and effective transportation, road repair is occasionally necessary. India is one of many nations that spend between 20 and 50 percent of their total budget on maintenance [2, 3]. The World Road Association [3] defines preventive maintenance as any type of maintenance.

As the infrastructure of the road ages, so does the demand for repair. Pavement failure will result from surface cracks, shadow cracks getting worse, and other issues caused by these aging pavements. Because new road construction and ongoing maintenance are interspersed, the pavement has not been able to reach its full service life. To improve or extend the life of pavements, a variety of cutting-edge designs, processes, and operations are emerging in India and around the globe.

II. INDUCTION HEATING

After a few years, bitumen will begin to deteriorate as a result of environmental causes and lose its ability to adhere to aggregate minerals, which will cause cracks to spread. The rift cannot be healed at this time, especially while it is still developing. Additionally, it has been demonstrated that during this resting interval, the pavement's healing rate rises as the temperature does [8].

This technique also causes the mixture to heat unevenly; in order to address this issue, induction heating technology, a recently developed technology, is employed [8, 9]. A very tiny quantity of highly refined steel filaments, or fibers, are added to the bituminous mix throughout the production process [8]. Through induction, the bituminous layer can be heated with the aid of these steel fibers located within the upper or wearing surface layer [8–10].

The concept of induction heating of bituminous roads to melt snow and ice using induction energy was pioneered, developed, and patented by Minsk [12]. Wu et al. (2006) [13] studied induction heating in bituminous pavement using conductive carbon fibers, carbon black, and graphite as conductive media and demonstrated that adding conductive fibers to the mix was more effective than adding conductive fillers.

Research by Garcia (2009) [14] and Liu et al. (2010) [15] initiated the development of a self-healing bituminous pavement mix by incorporating electrically conductive steel and wool fibers into the bituminous mix. In the induction process, we send an alternating current (AC) through a coil and generate an alternating electromagnetic field [14,15]. The "Joules effect" causes heat to accumulate in the conductor as induced currents flow against the electrical resistance of the conductor [14, 15]. Steel fibers are added to the bituminous mix to improve its conductive qualities, which also impact the mix's mechanical and physical characteristics. In order to assess this, Garcia et al. [14] examined 25 distinct mixtures that shared the same bitumen content and gradation but took into account four different steel wool diameters, two different fiber lengths, and four different percentages. Furthermore, test samples with three distinct types of damage—saltwater damage, water damage, and aging—have been subjected to particle loss experiments to assess the impact of the steel fiber added to the mixture [16]. The results showed that steel wool fibers do not become better [15,17]. Conversely, steel wool fibers have the ability to alter the mix's air void ratio and decrease its susceptibility to particle loss [15, 18].

As seen in Figures 1 and 2, Liu et al. (2010) [15] showed that adding steel fibers to porous asphalt concrete strengthens the mastic (bitumen, filler, and sand) and can postpone the raveling effect in bituminous pavements.

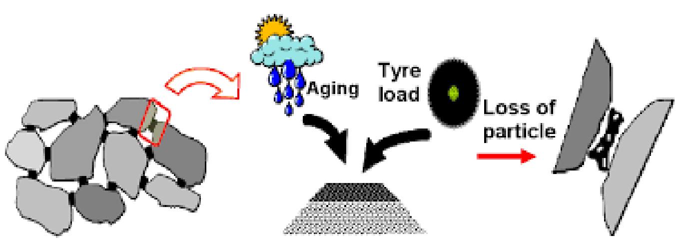

Fig.1 Raveling effect in bituminous pavement

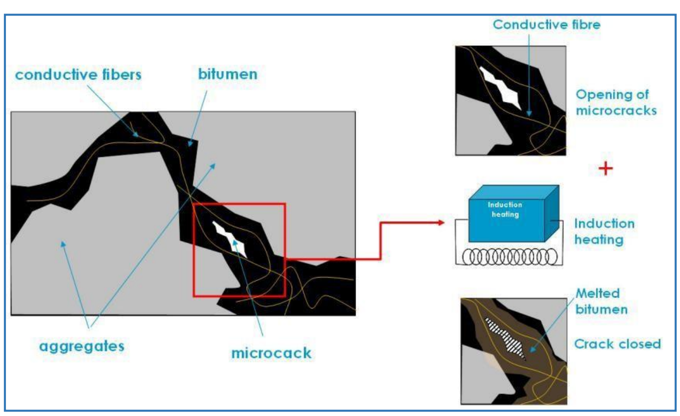

Fig.2 Induction Healing in Porous Asphalt

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While induction-based self-healing is the most widely used method among them, it has certain drawbacks as well, including drainage issues, aging bitumen material, corrosion of steel fibers, and conductivity from overheating. Further research is required to properly control variables like temperature, fiber dosage, heating duration, and other aspects of this method in order to achieve optimal outcomes and successful application [14–17].

According to Garcia et al. [14], the mastic sample's resistance would keep declining as the amount of conductive addition increased. The resistivity of the sample won't decrease as the volume is increased up to a certain point. If the amount of steel wool in the mixture is increased further, it could solidify and form cluster balls. As a result, their study's steel wool content is restricted to roughly 6%.

III. Conductive Particles Used for Induction Healing

Most steel fibers and steel wool are commonly used in induction and electromagnetic heating processes to heat asphalt mixes. Table 1 presents the methods by which Liu et al. [8, 9, 16, 17] and Garcia et al. [10, 18] heated asphalt mixes using induction and microwave radiation using steel wool. In order to facilitate fracture healing, induction and microwave radiation heating techniques were also applied to steel shavings, carbon fibers, and cutlery steel wool [19–21].

Table-1 List of some research studies on the different types of material used for induction healing

Healing type	References	Material used	Diameter (µm)	Length (mm)	Temperature (ºC)	Duration of Heating(s)	Relevant Conclusion
Induction heating	Liu et al. (10)	Steel Wool	8.89-12.7	3.2/6.4/9.5	169	180	The best-performing porous asphalt concrete had a bitumen content of 8% by volume and a steel wool length of 9.5 mm. [10]
		Steel Wool	6.38-8.89	6	137		
Induction heating	Garc'ia et al. (17)	Steel Wool	8.89-12.7	1-15	--	180	-As the amount of fibers rose, the temperature climbed linearly [17]. -The mechanical resistance of the asphalt concrete mix is unaffected by changes in the quantity of steel wool fibers or the timing of mixing, according to Marshall tests [17].

Healing type	References	Material used	Diameter (µm)	Length (mm)	Temperature (ºC)	Duration of Heating(s)	Relevant Conclusion
Microwave heating	Wang et al. (19)	(AS4) Carbon fibers	7.1	6.35	--	120 (at 1100 W)	-By adding enough carbon fibers, the sample's electrical resistance can be reduced. More microwave radiation or heat for healing can be absorbed by it. As a result, utilizing carbon fibers to repair cracks requires less heat or energy [19]. The optimum healing performance or outcome is seen in -3% of AS-4 carbon fibers by bitumen weight [19].

IV. MICROWAVE HEATING

Another way that bituminous or asphalt pavement might self-heal is by the use of microwave radiation. Microwave electromagnetic (EM) waves are similar to radar, ultraviolet (UV rays), and infrared (IR rays) in nature [20]. Microwave heating converts the material's intrinsic electromagnetic energy into heat. Nonetheless, the intensity or heat of electromagnetic radiation and its absorption are determined by the photon wavelength, or color, which varies across a wide range [20].

This establishes the heat transfer rate; for instance, black or dark surfaces have higher photon wavelengths than transparent surfaces, which is the case for the extremely effective [20, 22]. The homogeneous dissipation of heat or energy is aided by this phenomenon. Steel wool fibers have the ability to absorb electromagnetic radiation when they are in the microwave area [22]. Through a combination of many processes, including dissipation, steel fibers may absorb microwaves and transform them into heat [23].

The asphalt and aggregates get the converted heat or energy [23]. Newtonian flow of asphalt is produced during microwave heating because of the influence of temperature on asphalt, which aids in filling in mix cracks.

V. CONCLUSION

These techniques or technologies are effective and practical for treating and maintaining road pavements, and they have a great deal of potential to extend the service and design life span of asphalt pavements, according to a thorough review of the research work done on the advancement of self-healing. By raising the binder's temperature absorption, the innovative self-healing technology—which uses microwave heating and induction healing—can strengthen its resilience to fatigue under frequent and repetitive traffic loads.

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