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A Review Work on High Frequency Induction Curing of Porous Asphalt Concrete

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ABSTRACT

Induction heating method is a well known process to produce heat in a localized area on a susceptible metallic object. High frequency power, a work coil and an ancillary instrument part is the basis of induction heating. It is used in industrial and domestic areas where uniform and rapid heating is absolutely essential. As it is highly needed, in this research work, the effectiveness of induction heating will be verified by different curing methods. Firstly to initiate the asphalt concrete curing by high frequency induction heating so that the concrete become durable, electrically conductive and appropriately adjusted for induction heating, steel wire mesh/GI wire mesh is employed which is a good conductor of electricity. Now when micro cracks are likely to occur in asphalt product, the temperature of the asphalt material can be made high by induction heating of the steel wire mesh/GI wire mesh due to which the micro cracks are repaired itself and cracks are repaired by the increased temperature curing of bitumen by the physical process of diffusion and flow of the material. Consequent upon the repair, pre repair of small cracks, major cracks fail to occur protecting the road and thus ravelling of the road prevented to a great extent.

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1. INTRODUCTION

1.1. Ravelling on Dutch Highways

To reduce traffic noise in highways and busy roads porous asphalt concrete (PA) wearing is frequently done. Netherland first used it in 1972 [1] and then they begin to use it in mass scale [2]. Recently about 90% of the roads in the Netherlands are surfaced with porous asphalt concrete [3]. Open graded porous asphalt concrete replacing the conventional dense-graded asphalt concrete is employed which has following advantages:

a. Traffic noise is reduced by 3-4 dB as compared to dense-graded asphalt concrete roads [4], [5].
b. Outside drainage of water-During rainy season or water-logging, water drains out through the porous asphalt to the side of the road. It prevents spray and splash improving visibility and driving safety particularly in rainy season [6]. Further it keeps the road dry which bears the longevity of the road.

Ironically the smoothness and eye-catching aspect of porous asphalt surface is short-lived due to rapid ageing process, abrasion and clogging [7]. The largest defect in porous asphalt concrete is the poor performance in terms of ravelling, as shown in Figure 1. Porous asphalt is highly susceptible to ravelling, the process by which aggregate particles are lost from the road surface. Ravelling is influenced by climatic factor and traffic burden. According to Hagos, ravelling invariably occurs as the relaxation capacity is decreased, stiffness is increased and onset of small cracks in the binder due to aging [8]. Chemical spills, rough use, fire lighting will also add to ravelling. Finally particles are removed by the moving vehicles on the road. Ravelling takes time to start after new road formation. It may take 2 years to 7 years or more after paving. Ravelling leads to other serious consequences like formation of ditches because once some stones are removed, other more and more stones will be thrown away due to loosening [9]. The most common cause of failure of surface wearing is ravelling of porous asphalt surface layer [10], [11]. Due to ravelling noise reduction property is greatly hampered and also there is reduction in preventing the skidding resistance of asphalt. Early maintenance is required to prevent the breaking of the asphalt layer which occurs within a short time like within a few months to a few weeks in severe cases [12].

Figure 1. Ravelling in porous asphalt surface layer

1.2. Potential cause of ravelling

Ravelling in a porous asphalt surface wearing course usually starts slowly, but after 7-9 years it develops very quickly because of the domino-like effect of gap growing. When one stone is removed, adjacent stone lacks the support and easily removed and process accelerates in an exponential way resulting in rapid deterioration of the asphalt process [9].

1.3. Objectives and Approach of this Work

Ravelling is the starting point of road degradation. The so called skid resistance and noise reduction function of porous asphalt surface is greatly reduced and maintenance becomes inevitable. Ravelling is the main cause for maintenance or renewing of the top layer of porous asphalt pavement. To improve the durability, integrity and for getting the other advantages of porous asphalting, ravelling is to be prevented as much as possible by hook or crook. Ravelling prevented, road protected to a great extent. Hence here lies the importance of porous asphalting in a scientific and methodical way preventing ravelling. So, the objective of this project is to prevent ravelling of road by porous asphalt surface wearing.

To achieve this goal, a high frequency induction heating approach (namely, activating the curing process of porous asphalt concrete through induction heating) will be used. Steel wire mesh/GI wire mesh are added to a porous asphalt mixture to make the road electrically conductive and suitable for induction heating. When very small crack is going to occur in the asphalt mastic then by heating steel wire mesh/GI wire mesh externally by any means causes curing bitumen by virtue of its physical property of diffusion and flow and thus resulting in repair the cracks in a smoother way. As the small cracks are closed, formation of major cracks are thus prevented, ravelling of the road is prevented. The heating process helped by steel wire mesh/GI wire mesh on the porous asphalt wearing course can be repeated if cracks reappears.

2. APPLICATION OF POROUS ASPHALT CONCRETE

Porous asphalt surface wearing course (open graded friction course) was originally developed to prevent skidding on wet pavements in the 1930s in the US and was generally applied on highways and airports in 1970s. It was first used in the Netherlands in 1972 [1]. Since then, more and more Dutch highways are surfaced with porous asphalt concrete to reduce traffic noise, which is a very important environmental issue in the Netherlands with many urban areas close to the major highways.

3. ADVANTAGES OF POROUS ASPHALT CONCRETE

a. Reduction of pavement noise levels
b. Better skid resistance
c. Reduction of splash and spray
d. Water accumulation on road is avoided
e. Improved vehicle adherence and visibility
f. Reduced water contamination
g. Less light glaring
h. Reduces fuel consumption
i. Less wear and tear of vehicle tyre
j. Reduced traffic accidents

4. DISADVANTAGES OF POROUS ASPHALT CONCRETE

a. Relative shorter service life
b. Higher construction costs
c. Maintenance will be required

5. RAVELLING ON POROUS ASPHALT CONCRETE

The longevity of asphalt repair is a matter of concern, because the attractive feature of porous asphalt does not last long due to aging process, ravelling and clogging. Ravelling, which is the loss of aggregates from the road surface (as shown in Figure 2), is the main defect on porous asphalt surface wearing course [11], [13]. Ravelling is a failure at the surface of the pavement occurring within the stone-to-stone contact regions. It is caused by occurrence of micro-cracks, heavy traffics, water logging etc. Finally it leads to holes, ditches. It hampers noise reduction, skid reduction etc. For ravelling, maintenance is required much more frequently than dense graded asphalt road. To extend the lifetime of porous asphalt road, ravelling must be prevented.

Figure 2. Serious ravelling on highways Amsterdam A1 (left) and The Hague A4 (right)

6. SELF CURING OF ASPHALT CONCRETE

6.1. Concept of Self Curing

Self curing can be defined as the built-in ability of a material to automatically cure (repair) the damage occurring during its service life [14], [15]. The properties of a material degrade with time as a natural process. These cracks can grow and ultimately lead to full scale failure. Micro-cracks appear and lead to macro-cracks and ultimate failure is not cared for. Day by day ongoing research is going on to improve the quality of material, materials with self curing components to improve the service life of the material. If we use a material which itself has the property to correct the damage by its own composition will reduce the production cost, maintenance cost thus increasing its cost-effectiveness [16].

The dominant research on self curing materials is done in the field of polymers. The first patent of polymer was used in 1966. It was the polymer with self-curing property. Craven developed reversible cross-linked polymers. It was condensation polymers where pendant furan groups were cross-linked with maleimides [17]. These polymer could reverse to their cross linked state after cracking. However, the potential of such polymer failed to satisfy the process.

In 1994, Dry developed an active and a passive cracking repair method by smart timed release of polymerizeable chemicals from porous and brittle hollow fibers into cement matrices [18]. As shown in Figure 3 (left), the active cracking repair system contains porous fibers coated with wax and filled with methyl methacrylate. When a crack occurs, low heat is applied to the cement matrix, wax is melted and the methyl methacrylate is released into the matrix. Subsequent heating make the methyl methacrylate polymerize to close the crack. In the passive crack filling method, loading, which causes micro-cracking in the cement matrix, breaks the brittle hollow glass fibers to release the chemicals Figure 3 (right).

The first completely autonomous synthetic self curing material was reported by White et al an example of a polymer composite with microcapsules [14]. This curing concept is illustrated in Figure 4. In a structural composite matrix, a microencapsulated curing agent with a catalyst which can polymerize the curing agent is embedded. When a crack meets the embedded microcapsules, it breaks and releases the curing agent into the crack plane through capillary action. Embedded catalyst triggers the polymerization of curing agent and thus closes the crack. Research has been conducted successfully on creating self curing materials.

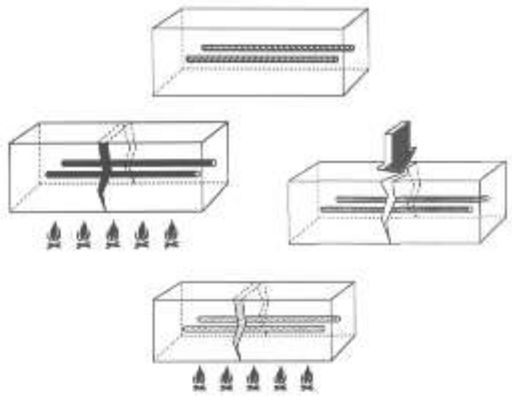

Figure 3. Design for timed release of polymerizeable chemicals to repair cracks and fill cracks: (left) by melting of the coating on porous fibers, (right) the brittle fiber breaks under load [Dry 1994]

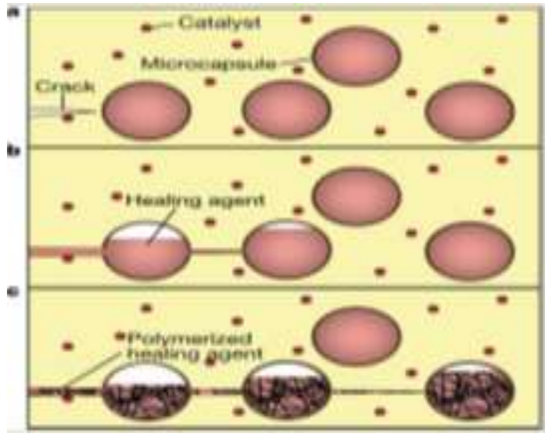

Figure 4. The self curing concept with microcapsules [White et al 2001]

6.2. Self Curing of Asphalt Concrete

Asphalt concrete, like other self curing material can repair the crack autonomously. When asphalt is subjected to a rest periods, it regains its physical strength and stiffness. It has been shown by the laboratory test and also in the field [19]-[21]. Bazin and Saunier has depicted that 90% of the original resistance was recovered when given rest under pressure at 25 ⁰C [19]. It is verified that half of the strength was regained if subjected to one day rest. Consequent upon the finding, further studies were done regarding strength recovery in relation to rest period. Castro and Little by their experimental study have shown that fatigue life can be extended when the asphalt is subjected to rest period [22], [23]. Field experiments also demonstrated the curing property of asphalt concrete. By surface wave measurement, Williams et al opined that stiffness recovers when it is given 24 hours rest [24]. It has been noticed that cracks in winter time disappeared during summer time. As a result, curing plays an important role in shifting laboratory fatigue to in-situ fatigue life [25].

7. INDUCTION CURING OF POROUS ASPHALT CONCRETE

7.1. Induction Heating Technology

An alternating magnetic field will induce currents in an electrical conductor. This process of generating electrical currents in a conductor by placing it in an alternating magnetic field is called Faraday's electromagnetic induction. This induced current will flow electrical resistivity of the conductor, generating heat in the conductor by "Joule effect" and this heating method is called induction heating [26]. It uses high frequency electricity and heat electrically conductive materials [27]. It has following advantages over convection, radiation, open flame or other heating methods. First, it is very efficient as it converts 90% of the consumed energy to useful heat. Secondly heating by induction is done without contact with heat. So it does not contaminate the work piece heated. Thirdly, product warpage, distortion and rejection rates are minimized as the heat is induced within the part itself by joule heating. Fourthly, induction heating is a quick process as heat is produced inside directly and instantly. There is no warming up or cooling down cycle. Fifthly, heating by induction does not require open flame, torch heating or any other method of direct heating. Once the process is setup and initiated, there is no tension of thinking or variation. It is consistent and repeatable thing. Finally, the working environment is improved as there is no smoke, pollution material or wastage of heat [28]. In modern manufacturing processes like bond hardening, metals softening etc, induction heating have wide application. The existing induction heating technique can be applied on the asphalt concrete road to increase the temperature and thus the cracks are closed by self curing property of bitumen. The first step of applying induction heating is to make the process asphalt electrically conductive which is the essential requirement for induction heating by induction energy. Conductive asphalt concrete has been prepared successfully by many researchers. In the next paragraph, a brief review will be conducted on conductive asphalt concrete.

7.2. Conductive Asphalt Concrete

Conduction of electricity by asphalt concrete is essential requirement. To achieve this property, components like graphite or fibers need to be mixed to the asphalt substance. In 1960, first test was done to control snow and ice accumulation [29]. The conductive asphalt concrete was made by the addition of graphite. Very recently, Wu et al in their research work, made electrically conductive asphalt concrete with the addition of conductive carbon fibers, carbon black or graphite to the mixture of asphalt [30]-[32]. In addition, Garcia et al made conductive asphalt mastic by addition of steel fiber and used induction heating to heat the mastic to enhance its curing properties [33], [34]. Garcia et al showed that the conductivity is proportional to the volume of electrically conductive particles in the mixture. They also showed that there is optimum volume content of electrically conductive particles for each mixture [35]-[37]. As discussed previously, heating by induction and the property of conductive asphalt concrete made it possible to close the cracks in the conductive porous asphalt layers by high temperature self curing of bitumen [38]-[40]. This approach, using induction heating to activate the self curing process of bitumen, is named induction curing.

8. PROPOSED SCHEME

Here a new system is proposed which will involve a high frequency induction heating for the curing of asphalt concrete road. Here the working coil of the high frequency inverter is the inductive coil (spiral shape) of the device and the asphalt concrete road along with GI wire mesh is treated as work piece. The proposed device employing the high frequency induction heating system rotated over the cracked concrete asphalt road. As a result rapid alternating magnetic field flux is produced which cuts the GI wire mesh. Thus the eddy emf is generated due to which, eddy current is circulated within the work piece. Finally generated heat in GI wire mesh will melt the asphalt and cure the crack of the asphalt layer of the road highways. The complete proposed system is shown in Figure 5.

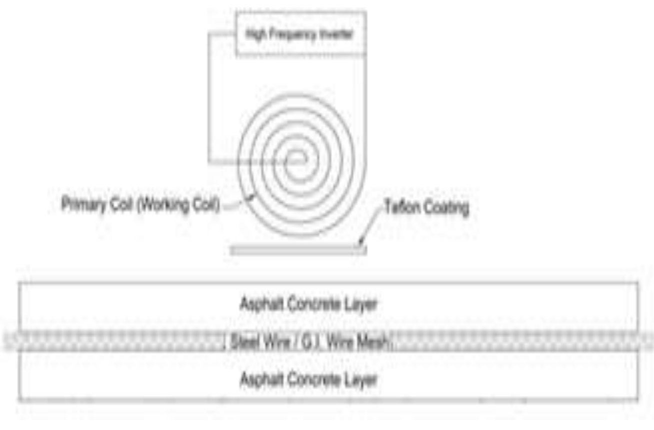

Figure 5. Schematic for proposed system

9. CONCLUSION

Observations from different literature, the following things can be outlined.

a. Porous asphalt concrete is the matter of interest to be used as surface material on road highways. It brings various benefits. Ravelling is the main reason decreasing the longevity of asphalt concrete and it is due to this ravelling, maintenance or resurfacing is required.

b. The strength and stiffness of asphalt concrete is required when subjected to rest period. The various factors affecting the surfacing rate of porous asphalt are properties of bitumen, the composition of asphalt mixture, climatic factors etc. Temperature greatly affects the curing property of asphalt concrete. When temperature is increased self curing rate is increased and it is caused in short time. This dependence on temperature makes us possible to cure the ravelling on roads, highways at a greater temperature. To achieve this, a heating process by high frequency induction heating is proposed in this relevant project.

c. The induction heating technology is made possible to be used in asphalt concrete curing. Conductive additive is added to the mixture for successfully curing. This is particularly required for heating.

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