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Experimental Study of Self -healing Asphalt by Steel Wool and Steel Fiber

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Abstract: *Self-healing asphalt represents a paradigm shift in the field of pavement materials engineering, offering a sustainable and cost-effective solution to mitigate the detrimental effects of cracking and deterioration in asphalt pavements. This paper provides an overview of recent advancements in self-healing asphalt technology, focusing on its mechanisms, materials, and applications. In this study, we conduct experiments test to evaluate the effectiveness of using steel wool and steel fiber as additives in self-healing asphalt. Self-healing asphalt is a special type of asphalt that can repair itself when it gets damaged, like when cracks or potholes form. The lab tests are performed to evaluate the function of self-healing asphalt with steel wool and steel fiber worked. The results of the study showed that adding steel wool and steel fiber improved the self-healing ability of the asphalt and made it stronger against cracking. Overall, this study helps us understand that we can make asphalt roads last longer and more durable. By using steel wool and steel fiber, we can create self-healing asphalt that can repair itself and stay in good condition for a longer time.*

Keywords: Self-healing asphalt, steel wool, steel fiber.

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1. Introduction

The implementation of self-healing asphalt offers numerous benefits, including extended pavement service life, reduced maintenance costs, and minimized environmental impact. Furthermore, it contributes to the overall sustainability of transportation infrastructure by reducing the consumption of natural resources and energy associated with frequent repairs and replacements. There are some main causes of cracks like traffic loads, freeze-thaw cycles, aging, inadequate base or subgrade, moisture intrusion, temperature variation, material quality and chemical damage etc. So, we are here to resolve these problems by introducing our research work on the 'self-healing asphalt'. In an era of characterized by innovation and sustainability, the self-healing asphalt has emerged as a groundbreaking solution to address the persistent challenges of road infrastructure. Roads, as the vital arteries of transportation, are subjected to relentless wear and tear due to the factors like traffic loads, environment stressors and temperature fluctuations. Traditional asphalt surface, while robust, are susceptible to the formation of cracks and fissures, necessitating costly and time-consuming maintenance. This project embarks on an exploration of the fascinating realm of self-healing asphalt, a revolutionary development at the intersection of material science and engineering. If the project work properly and give us proper result it is going to be great opportunity in the area transportation of civil engineering. It is going to become one of the best advancements in the area of transportation. It is going to be beneficial for the advancement area and also beneficial as the economy of the country by reducing the cost

Fig1. Common problems in roads across all over the city.

2. Mechanical method

By introducing induction heating in asphalt one of the most well-known methods is using by heating inductions it is well known it is easy for asphalt concrete to heal itself when we increase temperature and also shorten the time needed for full healing. To increase the tendency and to improve the properties of the asphalt some steel fibers are added into the

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mixture of asphalt. Steel fibers like steel wool, steel grit, steel fiber from recycled tires and steel shavings are used.

Fig. 2: Induction heating in laboratory

Fig. 3.: Induction heating in-situ

At a particular temperature the asphalt going to be heat so it could able to heat itself with the help of steel fibers used in mixture. We can use this technique to heal the more than once thiscould be repeated.

3. Literature Study

Literature review on the self heals asphalt through which it is considered that Self-healing asphalt is a type of pavement material that has the ability to repair cracks and damage on its own. The concept of self-healing asphalt involves incorporating healing agents or materials into the asphalt mixture. These healing agents can be activated when cracks occur, filling and sealing the damaged areas. Different types of healing mechanisms have been explored, including autonomous Healing, Capsule-based healing and vascular healing. Autonomous healing relies on the intrinsic properties of the asphalt to heal itself. When exposed to heat or moisture. Steel wool fiber and capsule-based healing involves embedding filled with healing Agents in the asphalt mixture, which rupture and release the healing materials to enhance the healing tendency.

Rizwan Ahmed, Dr. Naeem Aziz, Abdul Qudoos, Abdul Rasheed in International Research Journal of Modernization in Engineering Technology and Science (April 2021)

Bitumen mixture is likely to get aged and become stiff and shrink. Due to these actions, It generates cracks, to expand and fill those cracks bitumen has to be melted at a certain Temperature in order to avoid the asphalt deterioration. The fiber of steel wool is the key to enhance the asphalt concrete because of the conductive properties. These fibers of steel wool Are significant in increasing the dynamic modulus, resistance, moisture, and thaw resistance.

S. Xu, Alvaro García, Junfeng Su, Quantao

Liu, Amir Tabakovic, and Erik Schlangen in Self- healing asphalt review from idea to practice (2018) Tabaković et al. demonstrated that fibers even with optimum fiber design and fiber content in the mix are still unable significantly to improve large damage (crack) repair properties. Nevertheless, study demonstrated that fibers contain a potential in healing micro cracks within an asphalt mix, further demonstrated that optimum healing time for alginate fibers encapsulating rejuvenator is 20 h. illustrates successfulcrack closure (healing).

Tabaković and Schlangen stated that in order to develop a new generation of self-healing asphalt pavements, based on findings of currently available self- healing technologies, three specific working areas are identified that need particular effort. As a built-in property of asphalt, self-healing capacity has great potential to prolong service life of asphalt pavements. To achieve efficient and effective healing in asphalt, innovative ideas including induction healing and capsule healing have shown significant effect in laboratory. The asphalt induction healing system is very effective to pro-mote the healing capacity of asphalt pavement especially the healing of micro cracks. The induction healing system has been tested in the laboratory and validated in the field. Now, the technology is mature enough and waiting for the promotion from industry. The capsule healing system is capable of cracking site repairing of asphalt pavement. The healing mechanisms include both crack healing and aged binder rejuvenation. Various encapsulation methods have been investigated in the laboratory. For a larger scale application of the capsule healing system, more field-testing data need to be validated. Garia et al successfully reduce capsule using porous sand which is used as rejuvenator absorbing material, the sand granules are bound together and coated by hard shell made up of an epoxy cement.

Su et al manufacture polymer melamine-form aldehyde (MMF) micro capsule rejuvenator. RuiMicaelo, Tariq Al-Mansoori, Alvaro Garcia in effect of capsules containing sunflower oil on the mechanical behavior of aged asphalt mixture (July 2016). They designed a new type of capsules to improve the self-healing ability of asphalt mixtures was described and tested. These capsules are composed by a calcium alginate core where sunflower oil is entrapped and an external protective shell made of epoxy and cement.

4. Methodology

Before start any kind of project and work it is very important for us to have knowledge about the material we are going to use in our project. Self - healing asphalt is very unique and new advancement in the area of the transportation engineering. So, with the traditional Material we

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are going to use in this project we also need to study about the new material we are going to introduce in this area. As well as we also have to keep it in our mind the cost of the material beneficial and also affordable to make it successful in future. Here we also go to introduce some waste material to make it affordable and also the natural material to make it environment friendly.

Description and Selection

Asphalt Binder Description: Asphalt binder, also known as bitumen, is a viscous black substance derived from Crude oil. It serves as the glue that holds the aggregate materials together in asphalt pavement. Selection Considerations: The choice of asphalt binder is influenced by factors such as Climate, traffic volume, and the desired pavement lifespan. Different types of binders, including penetration-grade and performance-grade binders, are available to suit specific Project requirement.

.Fig.4: Bitumen

Aggregate Materials:

Description:

Aggregate materials are the crushed stones, sand, and gravel mixed with asphalt Binder to Create the pavement. They provide structural support and contribute to the pavement's overall Strength and durability.

Fig. 5.: Aggregate

Gradation and Mix Design:

Description: The gradation of aggregate materials and the mix design are crucial aspects of asphalt formulation. Gradation refers to the distribution of particle sizes in the aggregate blend, while mix design determines the proportions of binder, aggregates, and additives.

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Fig. 6.: Gradations and Mix Design

5. Preliminary-Testing of Material

The bitumen is the main ingredient used in the formation of the asphalt. It is sticky, black, highly viscous liquid or semi-solid form of petroleum It is a low grade of crude oil which is Composed of complex, heavy hydrocarbons.

While extracting it a lot of heat and effort must Be used to upgrade it to better the product.

As per IS code:

- VG-10 Bitumen
- VG-20 Bitumen
- VG-30 Bitumen
- VG-40 Bitumen

Pre testing – Testing of bitumen

Flash and fire test

The flash and fire test are conducted on bitumen to know the safe mixing and application Temperature value of particular bitumen grade. At higher temperature the bituminous material leaves out volatiles.

Fig. 7.: Pensky-Martens Apparatus and Thermometer

Observations:

Table 1: Flash and Fire Point Values

S. NO.	FLASH POINT	FIRE POINT
1	230°	290°

RESULT: - The temperature at which the flame application that causes a bright **flash 230°** and temperature at which the sample catches fire **290°C.**

As per IS code (1209 – 1978) the minimum value of flash point is 175°C and for fire point is180°C.

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Ductility test of bitumen

Ductility of bitumen is its property to elongated under traffic load without getting cracked in a road construction works. Ductility test on bitumen measure the distance in centimeters to which it elongates before breaking. This test is performed on the bitumen to check the sustainability of bitumen for use in road construction.

Fig: 8 Briquette Mould

Fig. 9.: Ductility Test Apparatus

Observation table:

Ductility test values for bitumen:

Table No 2 Ductility test values for bitumen

S. No.	Initial value	Final Value
1	0	82.5cm
2	0	79cm
3	0	81cm

Results: - The average value of the Ductility test = **80cm**

Testing of aggregates

Aggregate Sieve Analysis (According. to Indian Standard): Aggregate or gradation test determines the distribution of aggregate particles by size within a given sample. We perform test by taking the 5kg sample of aggregate

1 (a) Grain size distribution:

D_{60}=10.5mm

D_{30} = 6.5mm

D_{10} = 3.5mm

Cu = $\frac{D_{60}}{D_{10}}$ on simplifying, we get Cu = 3

Cc = $\frac{D_{30}}{D_{10}}$x$\frac{D_{30}}{D_{60}}$ On simplifying, we get Cc = 1.14

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As per BIS 2720 (PART-3,1985) Cu is less than 5 and Cc lies between 1 and 3 it shows the aggregates were non-uniform well graded aggregates.

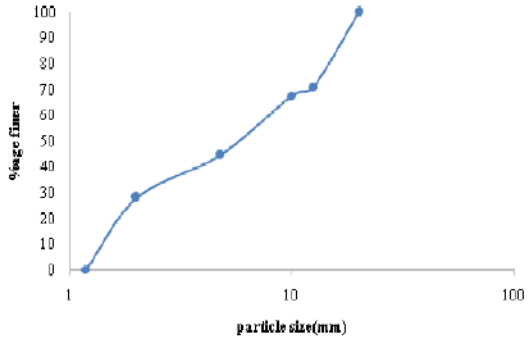

Fig 10 Sieve analysis

6. Experimental Methodology

After the material testing now, we have to perform the traditional testing on the asphalt sample. Preparation of conventional asphalt Firstly we have taken the coarse aggregate in proportion of 75% of coarse aggregate and 20% Fine aggregate. Pass then through sieves of 20mm, 16mm, 12.5mm, 10mm, 4.75mm, 2.36 mm. Heat the aggregates properly. After heating aggregate add 5% of bitumen in it Mix then well and heat them combine.

Preparation of specimen sample take a cylindrical mould of height 7.5 cm and diameter 10 cm. Put the hot mix of asphalt in the mould carefully.

Now compact asphalt in mould with rammer for 75 times. After that leaves the asphalt in mould for 24 hrs. To take the specimen out from the mould be continuously hit the base of the mould for 5 to 10 min.

Fig. 11 cylindrical mould

Preparation of asphalt by modification of adding steel wool. The procedure for this is same as conventional asphalt. But the change in the preparation is adding steel wool in the mixer up to 6% volume of binding material (Bitumen). Add the steel wool in the asphalt mix during heating. For moulding repeat the procedure of conventional asphalt. Preparation of asphalt by modification of adding steel fiber The procedure for this is same as conventional asphalt. But the change in the preparation is adding steel fiber in the mixer up to 6% volume of binding material (Bitumen). Cut the steel fiber in the piece of 1mm to 6mm length according to your need and mix it well during the heating. For moulding repeat the same procedure as before.

Observation table

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Table 3: Heating time surface temperature loading cycles for conventional asphalt

Samples	**Loadin gcycles**	**Surface temperature**	**Percentage**	**Heating time (min)**	**Healing /Recovery**
Sample 1 (conventional)	1	50° to 100°	0%	15min.	No change
		100° to 150°	0%	15 min.	No change
		150° to 200°	0%	15 min.	No change
		200° to 250°	0%	15 min.	Bitumen melted butaggregate fall down

Samples	**Loading cycles**	**Surface temperature**	**Heating time (min)**	**Percentage**	**Healing /Recovery**
Sample 2 (Steel Wool)	1	50° to 100°	15min.	0%	No change
		100° to 150°	15 min.	0%	No change
		150° to 200°	15 min.	30%	Lit bit change
		200° to 250°	15 min.	80%	Bitumen melted and spread in crack (let the mould rest for 3 to4 hrs. to regain its strength
	2	50° to 100°	15min.	0%	No change
		100° to 150°	15 min.	0%	No change
		150° to 200°	15 min.	20%	Cracked filled little bit
		200° to 250°	15 min.	70%	Bitumen melted and spread in crack (let the mould rest for 3 to4 hrs. to regain its strength

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Table No 4 Heating time surface temperature loading cycles by adding with steel fiber

Samples	Loading cycles	Surface temperature	Heating time (min)	Percentage	Healing /Recovery
Sample3 (Steel Fiber)	1	50° to 100°	15min.	0%	No change
		100° to 150°	15 min.	0%	No change
		150° to 200°	15 min.	35%	Little bit bitumen but crackednot filled properly
		200° to 250°	15 min.	85%	Bitumen melted and spreadin crack (let the mould rest for 3 to 4 hrs. to regain its strength)
	2	50° to 100°	15 min.	0%	No change
		100° to 150°	15 min.	0%	No change
		150° to 200°	15 min.	25%	Crack filled little bit bitumenmelted and spread crack
		200° to 250°	15 min.	75%	Bitumen melted and spreadin crack (let the mould rest for 3 to 4 hrs. to regain its strength)

7. Result and Findings

Embarking on a pioneering exploration, our study unveils the extraordinary self-healing process of asphalt, fortified by the infusion of steel wool and steel fibers. In this chapter we are going to compare our results with conventional asphalt and after that we compare it with modified asphalt by and steel wool and steel fiber.

Self-healing asphalt test

Conventional asphalt

In this we are going to compare the self-healing capacity of conventional asphalt and after adding the steel wool and steel fiber in the asphalt. Conventional asphalt took 15min to 20min at temperature 250° to 300° to melt the bitumen but it heats up only the upper portion of asphalt around 1 cm the below area of this didn't get heat up properly that's why bitumen didn't melted and this did not fill the crack due to low interlocking capacity of asphalt.

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Steel wool

The orange line shows that after mixing the steel wool in the asphalt mixture it gives us beneficial results as compare to normal asphalt it took 15min to melt the asphalt at 150° to200° temperature and healed 30% in first loading cycle and 20% in second loading.

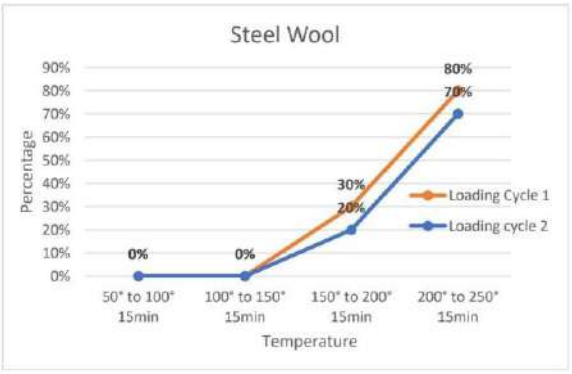

Fig. 12.: Steel wool graph

As Cycle shown in blue line. When we rise our temperature 200° to 250° for 15min. in in which during first loading it healed 80% (orange line) and after second loading blue line show that ithealed 70% (blue line) in this, we observe that steel wool in self-healing asphalt serves as a catalyst for the healing process.

When cracks occur, the steel wool reacts with specific additives in the asphalt mixture, inducing exothermic and endothermic processes that helps seal the cracks. This promotes durability and extends the lifespan of the asphalt by preventing water penetrationand further damage.

Steel fiber

The orange line indicates the result after mixing the steel fiber with asphalt mixture. It gives us beneficial results as compared to normal. Asphalt normal and with steel wool. It interlocks the asphalt together and make a strong bond. After first cyclic loading when temperature is provided 150° to 200° for 15min it healed 35% (orange line) and when we provide temperature 200° to 250° for 15min. it healed 85% (orange line). After providing second cycle of loading at temperature is 150° to 200° for 15min it healed 25% (blue line) and when temperature 200° to 250° for 15min it healed 75% (blue line). In this we observe that steel fibers in self-healing asphalt play a reinforcing role by enhancing the mechanical properties of the asphalt mixture. These fibers help prevent cracking and improve the overall durability of the asphalt pavement.Additionally, in the context of self-healing asphalt, the steel fibers can aid in the healing process by bridging and stabilizing cracks that may form over time, contributing to thematerial's ability to recover from damage and extend its service life.

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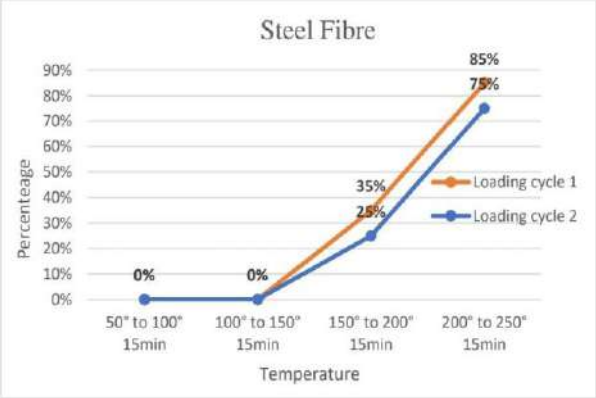

Fig. 13.: Steel fiber graph

8. Conclusion

In our whole study as a built-in property of asphalt, self-healing capacity has great potential To prolong service life of asphalt pavements. To achieve efficient and effective healing in Asphalt,innovative ideas including induction healing and capsule healing have shown Significant effect in laboratory. The asphalt induction healing system is very effective to pro-Mote the healing capacity of asphalt pavement especially the healing of microcracks. The Induction healing system has been tested in the laboratory and validated in the field. Now, the Technology is mature enough and waiting for the promotion from industry we elucidated some The potential benefits of self-healing asphalt technology in material performance, Environmental and social benefits will undoubtedly stimulate interest for the wider Use of self-healing technology in asphalt pavement design and construction. The incorporation of both steel wool and steel fibers in asphalt demonstrates a significant enhancement in the overall durability of road surfaces. The presence of these steel components contributes to improved crack resistance, mitigating the formation of surface flaws and extending the lifespan of the asphalt. Steel fibers act as effective reinforcements, adding structural integrity to the asphalt Mixture, particularly in high-stress areas. The use of steel wool complements steel fibers by further reinforcing the asphalt Matrix, enhancing its ability to withstand varying weather conditions and heavy Traffic loads. While the combination of steel wool and steel fibers shows promise, challenges Such as uniform distribution and cost-effectiveness must be addressed for widespread implementation.

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