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## Table of Contents

# Epoxy reinforced asphalt composites: their applications, failures, changes in mechanical properties due to reinforcement addition and curing kinetics

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## Abstract

The application of asphalt is mainly in paving roads. It can also be used for various other purposes. The versatility of asphalt makes it such a widely used material. Since it is widely used, good mechanical properties and a longer lifetime is desired. Failure occurs in asphalt composites when the material no longer holds its original shape and develops material stress which causes issues. This review addresses the different failures of asphalt composites and their causes, improvement of mechanical properties by reinforcement addition and different test procedures to gain a better understanding of the failures. Even a slight improvement of this composite material might help reduce the maintenance cost and also the number of casualties all around the world.

## Introduction

Road paving is an integral part of transportation infrastructure. Pavements built with asphalt concrete makeup most of paved roads globally. The use of composite asphalt is not limited to roads only. Runways, track beds, playgrounds, tennis courts, barn floors, harbors are just a few of the areas of application. Asphalt composites are also commonly used in buildings and as coatings. Asphalt composites are a popular paving material because of their low initial cost compared to other alternatives, their availability, their ease of construction, and their ability to be used in low-traffic areas. Through weathering and continued use, asphalt pavements degrade and require multiple maintenance operations during their intended life. Producing better performing asphalt is always achieved through refinement and processing improvements. Therefore, one common strategy to extend the life of asphalt pavements is to modify asphalt concrete by incorporating new additives into the bitumen or asphalt mixture. There are many different types of modifiers, including various resins, rubbers, polymers, metal complexes, fibers, and chemicals. Epoxy resin is the first choice as it has excellent mechanical and adhesive properties. It cures at room temperature and shows almost no shrinkage after curing. Excellent corrosion resistance and excellent contact with water. It can also be cost-effective and a major factor in material selection for composites.

## Distinction between asphalt and bitumen

The words asphalt and bitumen are often used incorrectly to define the same thing. Asphalt is a compound of aggregate, sand and bitumen. Bitumen acts as a liquid binder that holds the asphalt together. Road surfaces that are only sealed with bitumen are also common. In this case, a layer of bitumen is applied, covered with aggregate, and the process is repeated to obtain the two layers.

Asphalt pavements tend to be more durable, with a layer thickness of about 22-40 mm and lasting more than 20 years. On the other hand, bitumen-sealed surfaces and walkways are considered less durable. The layer thickness is about 10-20 mm and the lifetime is about 5-10 years. In areas with little or no traffic, bitumen is an excellent and inexpensive alternative.

Asphalt pavement is considered smooth and non-slip. This ensures driver safety and reduces noise, so it is used on highways and roads. The bitumen surface contributes to safety concerns as it allows for a noisier driving experience and tends to wear out tires, making it a good choice for sidewalks and roads with little traffic.

Asphalt reduces friction between vehicles and tires, improves fuel efficiency and reduces carbon emissions. On the other hand, bitumen increases frictional resistance, resulting in lower fuel consumption.

Asphalt is considered an impermeable material. Asphalt pavements do not leach, reducing the risk of groundwater seepage and contamination. In the case of bitumen, leaching can occur, leading to soil degradation and groundwater contamination.

Asphalt tends to be less sensitive to temperature and is adversely affected by extremely cold or hot temperatures. Weather conditions must be considered when deciding between asphalt and bitumen, as the bitumen surface is susceptible to temperature extremes and is soft and slippery.

## Failures

The problem of stress and failure in asphalt composite pavements is considered complex as multiple factors contribute to pavement degradation and failure. Improving the durability of asphalt composites requires a good understanding of failures and their causes.

Aged deterioration and oxidation of the asphalt film lead to deterioration. This degradation effect increases rapidly as the porosity of the asphalt composite retains excess water. Binder volatilization makes the asphalt composite surface brittle, leading to water penetration and further deterioration. Poor mix design, improper aggregate grading, and insufficient binder content lead to overlay failure.

The most common asphalt composite surface failure is alligator tear or map tear. This is a common type of obstruction and is caused by the relative movement of layers in the road. This fatigue failure occurs when high wheel loads are repeatedly applied. Moisture also plays an important role in this type of disorder. Localized vulnerabilities in the underlying base layer can also lead to this type of failure.

**Figure 1:** Fatigue cracking in asphalt pavement in Savoy, Illinois. Photo W. Buttlar [04]

Consolidation of pavement layers causes formation of ruts. A rut is a depression or groove worn into a road by the travel of wheels. This type of failure is caused due to repeated application of load along the same wheel path resulting longitudinal ruts. Wearing of the surface course along the wheel path results in shallow ruts.

**Figure 2:** Consolidation of pavement layers (Rutting) [18]

Shear failure and cracking are associated with the inherent weakness of composite mixtures. Shear failure causes upheaval of pavement material by forming a fracture or cracking. Excessive wheel loading and low shearing resistance of pavement mixture are primary causes of shear failure.

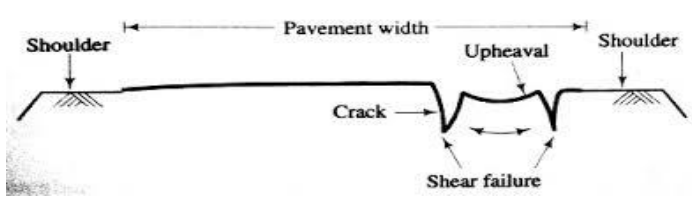


**Figure 3:** Schematic figure of shear failure [9]

**Figure 4:** Shear failure cracking  [18]

Frost heaving causes upheaval of localized portion of a pavement. The extent of frost heaving depends upon the ground water table and climatic condition.

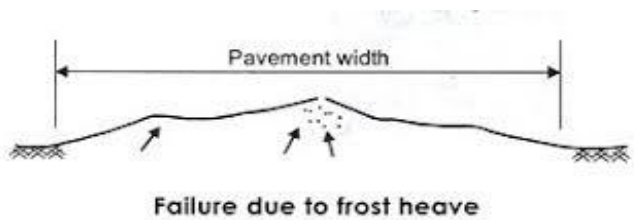


**Figure 5:** Schematic figure of frost heaving [9]

**Figure 6:** Pavement with frost heaving. [18]

## Epoxy Resins and Its Curing

The first commercial product of epoxy resin (ER), which was a reaction product of epichlorohydrin (ECH) and bisphenol A, was introduced by Devoe and Raynolds in 1947 [2]. Epoxy resin has gained increasing importance due to its extensive range of applications such as paints and coatings, adhesives, electrical insulation, electronics, aerospace industry, industrial tooling and biomedical systems [3], and more recently, in asphalt paving industry [4]. The rapid growth of ER application was mainly caused by their advantages such as

i. Low cure shrinkage
ii. High adhesive strength
iii. High mechanical properties, particularly strength and
iv. stiffness
v. Good chemical resistance
vi. Low creep
vii. High electrical resistance

As an alternative to conventional asphalt binder, epoxy asphalt (EA) has been initially applied in the pavement industry primarily due to its excellent rutting resistance since cross-linked structures were formed during the curing process. EA, generally a two-component composite system, often include ER as component A, and asphalt, curing agent, diluents, fillers, and toughening agents, as component B. The final composite made of components A and B was realized to possess great resistance to fatigue loading, moisture damage, and oxidation aging with the added polymeric structure of epoxy [5, 8, 9].

Epoxy can be divided into glycidyl epoxy and nonglycidyl epoxy based on the molecular structure and applications. The desired properties of cured epoxy can be well controlled through careful selection of ER, curing agent, modifier, component composition, and curing conditions [1, 11].

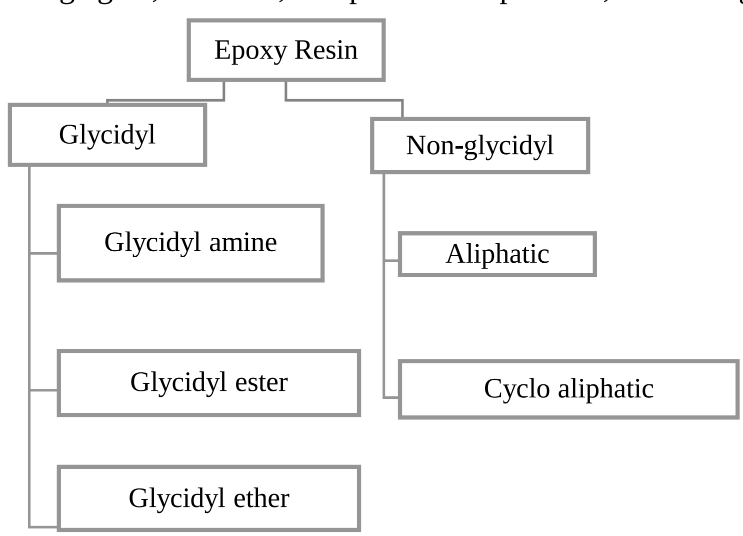


**Figure 7:** Classification of epoxy based on molecular structure

**Curing Agents for Epoxy Resin**: To overcome the poor mechanical, chemical, and heat resistance performance of uncured ERs, the linear ER can be cross-linked in the presence of curing agents to achieve optimum performance properties. The selection of curing agents depends on the application and processing methods, curing conditions, and the desired properties such as mechanical, chemical, thermal, and environmental limitations and costs. Curing agents are either catalytic or coreactive. The curing of ER can be completed through epoxy-to-epoxy ring-opening homopolymerization under catalytic curing agents or copolymerization under polyfunctional coreactive curing agents [11]. Catalytic curing agents can be used as initiators for epoxy-to-epoxy ring-opening homopolymerization, or as supplemental curing agent with polyamines or polyamides, or as an accelerator for anhydride-cured systems. Catalytic curing agents are generally inert under ambient temperature and indoor lighting, but they become active by heating or photoirradiation [3]. The commonly used catalytic curing agents include Lewis bases (e.g., tertiary amines), Lewis acids (e.g., boron trifluoride monoethylamine), and photoinitiators. Once under UV irradiation, photoinitiators produce a Lewis acid, which cures the ERs in the traditional way.

**Modifiers**: The properties and behavior of ER can be adjusted with the addition of diluents, fillers, and toughening agents [21]. Diluents can be used to modify the properties of ER, especially lowering the viscosity to improve the handling characteristics.

It should be noted that the optimum combination of the fractions of ER, curing agents, and modifiers should be determined for each specific application.

**Curing Methods of Epoxy Resin:** Besides epoxy resin and its hardener, the curing method also has a significant effect on the properties of epoxy. The methods for curing ER control the chemical reaction between epoxy groups and curing agents and thus the subsequent properties of epoxy products. Primary curing methods are chemical curing (under room or increased temperature), microwave curing, and radiation curing (electron-beam and ultraviolet curing) [40].

## Curing kinetics

The most commonly used epoxy resin is made from bisphenol-A and epichlorohydrine (ECD) and this resin is mixed with hardener (Curing agent) to form highly crosslinked 3D polymer networks that can enhance mechanical properties of resins. This process can also be termed as curing. Several curing agent can be used depending on the required properties. Most common curing agents are phenolic resind, amines, polyamines, polyamides etc**.** Various chemical reaction takes place during curing which can help to determine the kinetics or rate of cure required for a specific properties [1, 6]

Kinetic analysis of curing process represents a mathematical relationship between conversion, conversion rate and temperature. The most accurate method for investigating curing kinetics is Differential Scanning Calorimetry (DSC) under both isothermal and nonisothermal condition [18].

As curing of epoxy resin is an exothermic reaction, heat generated during this process is assumed directly proportional to the rate of reaction (or to the number of consumed reactive groups) and a function of time and temperature. Released heat during curing is measured by DSC method. The extent conversion or reaction ($\alpha_t$) is proportional to the released heat [18].

$$\mathrm{\alpha_t = \frac{Q_t}{Q_{utl}}}$$

$Q_t$ is the amount of heat evolved upto time t and $Q_{utl}$ is the total heat of reaction. When a system cured isothermally below glass transition temperature $T_g$ , due to vitrification it cured incompletely [18] Therefore total heat

$$Q_{utl} = Q_{iso} + Q_{res}$$

$Q_{iso}$ is the heat generated during isothermal cure and $Q_{res}$ is the residual heat release during the dynamic run of sample after isothermal cure [18].

$$\frac{d\alpha_t}{dt} = \frac{\frac{dQ}{dt}}{Q_{utl}}$$

The rate of reaction normally depends on temperature (T), extent of reaction ($\alpha_t$) and pressure (P) [10].

$$\frac{d\alpha}{dt} = K(T)f(\alpha)h(P)$$

For normal atmospheric condition pressure dependence is ignored and rate only depends on 2 variables T and α [18]

$$\frac{d\alpha}{dt} = K(T)f(\alpha)$$

$$\mathrm{K(T)} = \mathrm{A}\,\exp(-\frac{\mathrm{E}}{\mathrm{RT}})$$

Here A is the pre exponential factor, E is the activation energy and R is the universal gas constant [10].

Logarithmic derivative of equation $\frac{d\alpha}{dt} = K(T)f(\alpha)$ [10]

$$[\frac{\delta ln(d\alpha/dt)}{\delta T^{-1}}] = [\frac{\delta lnK(T)}{\delta T^{-1}}] + [\frac{\delta lnf(\alpha)}{\delta T^{-1}}]$$

If the conversion extent is constant (α).

$$\frac{\delta ln(d\alpha/dt)}{\delta T^{-1}} = -\frac{E_\alpha}{R}$$

For higher accuracy the well-known methods are kissinger-akahira-sunose method.

$$\ln\frac{\beta_i}{T_{\alpha,i}^2} = \mathrm{const} - \frac{E_\alpha}{RT_\alpha}$$

And Starink method [10]

$$\ln\frac{\beta_i}{T_{\alpha,i}^{1.92}} = \text{const} - 1.0008\frac{E_\alpha}{RT_\alpha}$$

β is the heating rate.

## Optimum Epoxy Content

A previous study showed the favorable percentage of epoxy added in bitumen to improve its properties.

**Material used:** VG 40 grade bitumen, fine aggregates, coarse aggregate, fillers, epoxy resin [13].

Different percentages of Epoxy resin in the bitumen mix were taken (1, 2, 3, 3.25, 3.5, 3.75 and 4). Stability, flow rate (deformation between no load and maximum load), air voids, softening point are observed [13].

**Stability vs. Epoxy content**

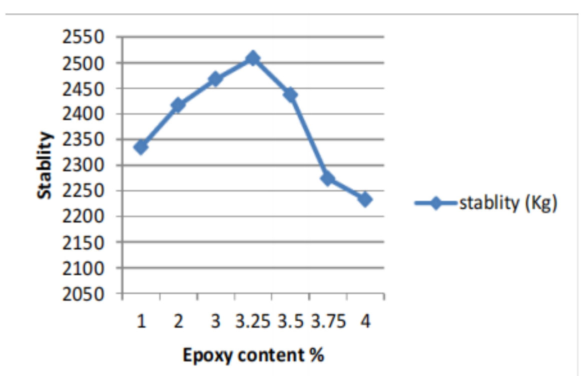


**Figure 8:** Effect of Epoxy Resin on stability of bitumen mix [13]

This graph shows that stability of bitumen mix increases gradually to epoxy content 3.25% and then decreases with further increase in epoxy content.

**Flow rate vs. Epoxy content**

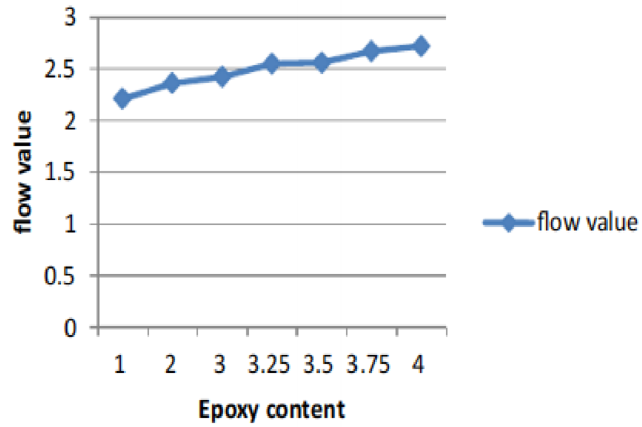


**Figure 9:** Effect of epoxy resin on flow value of bitumen mix [13]

This graph shows that flow rate of bitumen mix or asphalt increases with increasing epoxy content.

**Air void vs. Epoxy content**

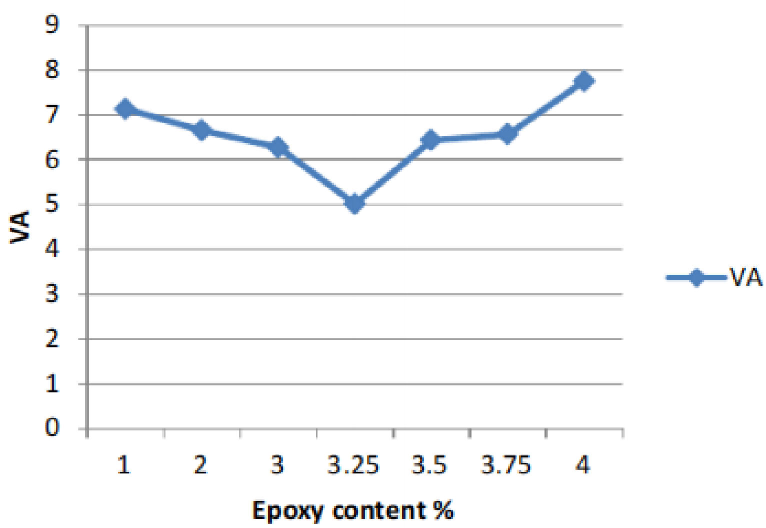


**Figure 10:** Effect of epoxy resin on air voids of bitumen mix [13]

This graph shows that $1^{st}$ air void decrease with increasing epoxy content in bitumen mix and bitumen mix with epoxy content 3.25% has lowest air void. After that air void increases with increasing epoxy content.

**Volume of mineral aggregates vs. Epoxy content**

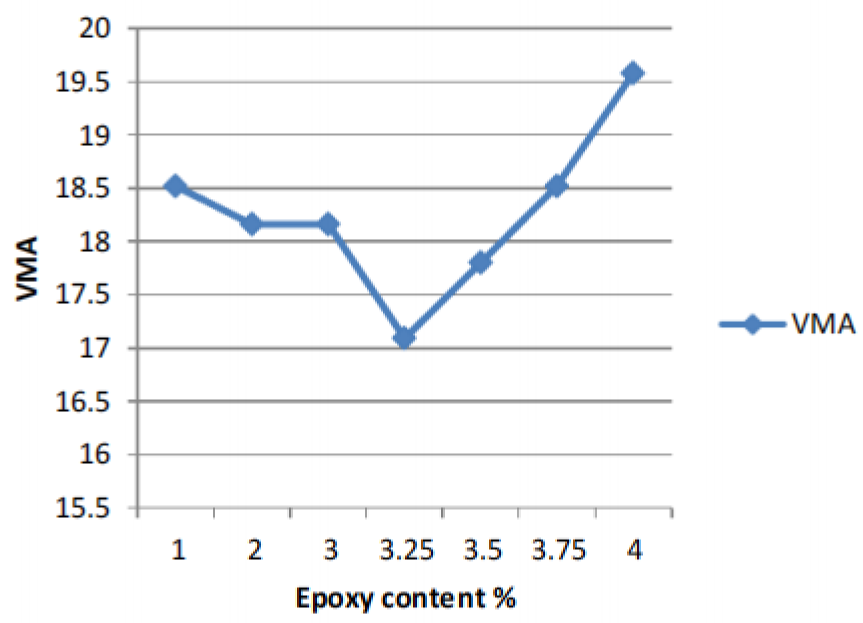


**Figure 11:** Effect of epoxy resin on volume of mineral aggregates of bitumen mix [13]

This graph shows that at first VMA decrease with increasing epoxy content in bitumen mix. And bitumen mix with epoxy content 3.25% has lowest VMA. After that air VMA increases rapidly with increasing epoxy content.

**Filled void vs. Epoxy content**

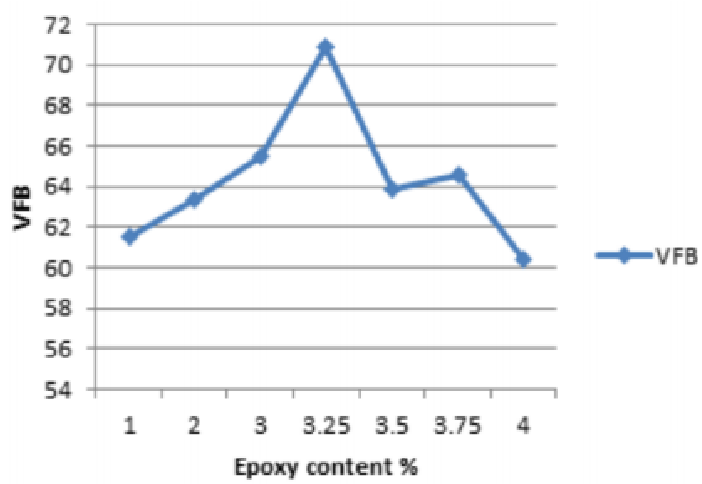


**Figure 12:** Effect of epoxy resin on voids filled with bitumen of bitumen mix [13]

From figure 5 we can conclude that, adding epoxy with bitumen will increase the void filling capacity gradually from 1% to 3.25% and then with increasing epoxy content in bitumen mix will fill less void.

**Softening point vs. Epoxy content**

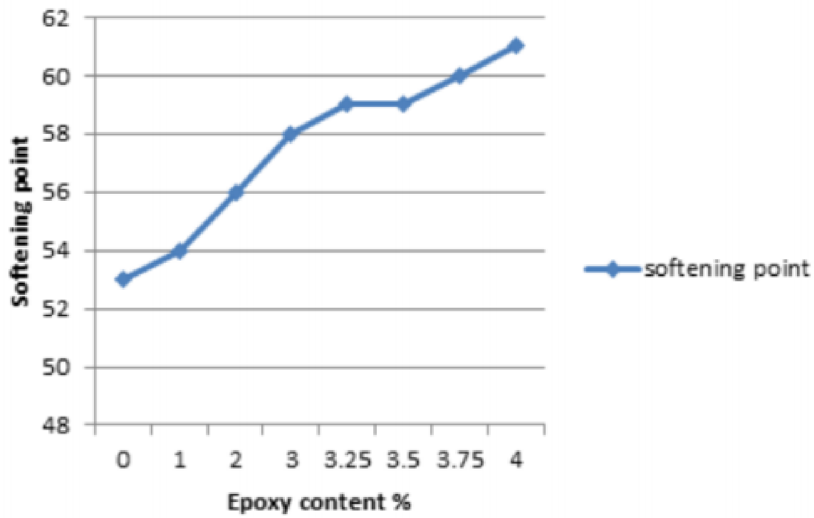


**Figure 13:** Effect of epoxy content on softening point of bitumen [13]

This curve shows that softening point increases with increasing epoxy content in bitumen mix. That means bitumen will be softened at higher due to higher epoxy content.

**Penetration value vs. Epoxy content:**

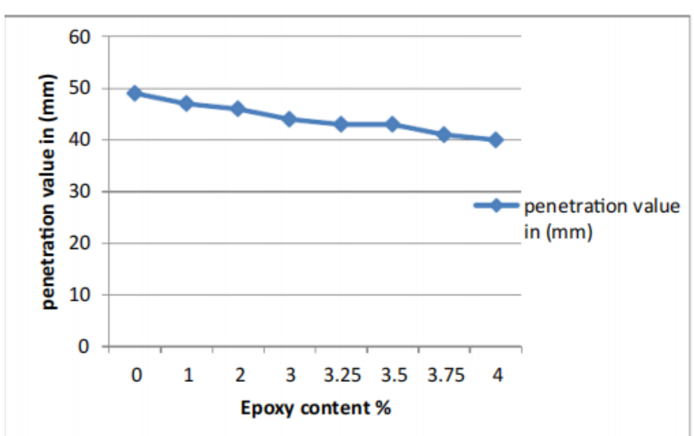


**Figure 14:** Effect of epoxy resin on penetration value of bitumen mix [13]

Figure 7 shows that penetration value of bitumen decreases slightly with increasing epoxy content in bitumen mix.

From all these graph we can come to a conclusion that 3.25% epoxy content in bitumen mix shows better properties because

viii. At epoxy percentage of 3.25 the stability of bitumen mixture is maximum which gives good chemical resistance
ix. Flow rate of epoxy bitumen mix is moderate at 3.25% epoxy content
x. Air voids of bitumen mix is lower at 3.35% of epoxy content ,that means lower change ti initiate crack
xi. Volume of mineral aggregates of bitumen is minimum at 3.25% of epoxy content
xii. Void filled with bitumen mix is highest at 3.25% epoxy content, which provide low shrinkage.
xiii. Softening point moderate at 3.25% epoxy content ,which indicates suitable use for summer season
xiv. Penetration value is also moderate at 3.25% epoxy content

Optimum 3.25% epoxy content with bitumen can give improved properties for epoxy bitumen mix or epoxy asphalt.

## Fiber Reinforcement

A major problem associated with asphalt concrete pavements is their durability through continuous heavy traffic and weathering. Incorporating fibers into asphalt concrete can improve mechanical properties such as durability, stability, stiffness, and fatigue behavior and crack propagation. Another important factor is binder leakage or premature deterioration leading to eventual failure of asphalt concrete, which can also be ameliorated by incorporating fibers. Polymer styrene butadiene styrene (SBS), polyethylene, cellulose fibers and rockwool are used to prevent bitumen leakage in asphalt concrete aggregates. Mainly fiber are used in asphalt for three main reasons:

I. to prevent drain down or raveling of porous asphalt (PA) and stone matrix asphalt (SMA),
II. to improve resistance to mechanical performance, i.e. cracking and rutting resistance and
III. to enable multifunctional applications [12].

Although a lot of natural fiber exist in nature and also a good number of fiber can be synthesized in lab but the choosing of appropriate fiber depends on better desired properties than others.

## Type of Reinforcing Fiber Used in Asphalt Concrete

A wide variety of fiber types has been used in asphalt concrete mixture including natural fibers (cellulose, lignin, date-palm, oil-palm), mineral (asbestos, rock wool), synthetic polymer (polyester, polypropylene, polyacrylonitrile, Aramid), and glass fibers. Recycled fiber material such as newsprint, carpet fibers, and recycled tire fibers have also been used.

Some fibers are their properties are listed below that can be considered as beneficial reinforcement in fiber-modified asphalt binder:

| Name of Fibers | Properties |
|---|---|
| Asbestos | Degradation temperature : 800 ℃<br>Tensile Strength : 2.1 Gpa<br>Modulus of Elasticity : 11.70 Gpa<br>Mohs hardness : 2.50-4.00<br>Water absorption (%) : 23.12 %<br>[11,14] |
| Polyester | Tensile Strength : 0.392 Gpa [11]<br>Melting point : 241℃<br>Water absorption : 2.43 % |
| Nylon | Tensile Strength : 0.264 Gpa [11]<br>Melting point : 195 ℃ |
| Aramid | Tensile Strength : 2.75 Gpa<br>Modulus of Elasticity : 62.00 Gpa |
| Steel | Tensile Strength : 0.95 Gpa<br>Modulus of Elasticity: 11. Gpa<br>Mohs hardness : 5.00 |
| Coconut | Tensile Strength : 175 Mpa<br>Elastic Modulus : 19-25 Gpa<br>Water absorption : 130-180% |
| Carbon | Tensile Strength : 1.33 Gpa<br>Modulus of Elasticity : 30.00 Gpa<br>Mohs hardness : 6.00 |
| Cellulose | Tensile Strength : 300-2000 Mpa<br>Elastic Modulus : 10-50 Gpa |

| | |
|---|---|
| Glass | Tensile Strength : 3.40 Gpa<br>Modulus of Elasticity : 72 Gpa<br>Mohs hardness : 6.50<br>[11,14.12] |

## Advantages and Potential Drawbacks of Fiber in Asphalt Concrete

### <u>Asbestos Fiber</u>

Mineral fibers include asbestos that is a naturally occurring fibrous silicate minerals in color green / red / yellow / white / gray / blue .Asbestos fibers are soft and flexible yet resistant to heat, fire, chemical and biological breakdown. They can also be mixed with cement, paper, textiles and other materials to make them stronger. However prolonged inhalation of asbestos fiber can causes serious and fatal illness which limits the uses of asbestos.

Addition of asbestos reinforcement with asphalt concrete will improve some of the properties of asphalt binder.

| **Advantages** | **Potential Drawbacks** |
|---|---|
| High abrasion resistance | Health hazard at high temperature |
| Thermal stability | Some may corrode or degrade because of moisture conditions |
| Improve Crack Resistance | |

### <u>Polyester Fiber</u>

Polyester is a man-made synthetic fiber usually obtained from petroleum. Polyester fibers can also be extracted from worn tires. One of the main problems with worn tires is contamination. Polyester fibers with low asphalt binder content increase resistance to fatigue and plastic deformation. It has been found that the mechanical properties of polyester fiber asphalt concrete (PFAC) are improved by polyester fiber reinforcement, and the adhesion resistance between fiber and asphalt is directly related to fiber content and asphalt content. Uniform fiber distribution is required to improve binder strength.

Some advantage and drawbacks of polyester fiber reinforced in asphalt

| Advantages | Potential Drawbacks |
| --- | --- |
| Resist cracking, rutting | The optimum asphalt content of mixture increase. |
| Increase fracture energy and toughness | Cost effectiveness not proven yet |
| High tensile strength | |
| Increase mix strength and stability | |
| Improve Crack propagation resistance [14] | |

## Nylon Fiber

Nylon is a synthetic fiber made from polyamide. They are particularly strong, light and elastic, stronger than polyester. Nylon fibers can be added to asphalt concrete in varying proportions. A proper proportion of nylon fiber reinforcement can improve the properties of asphalt concrete.

| Advantages | Potential Drawbacks |
| --- | --- |
| Increase resistance to permanent deformation | Air voids content of asphalt increase with increasing nylon fiber content [15]. |
| Lower the sensitivity towards temperature | |

## Aramid Fiber

Aramid or aromatic polyamide is a strong synthetic fiber. Excellent heat resistance, corrosion resistance, and light weight. The use of aramid fibers in asphalt concrete has become popular due to the improved mechanical performance of asphalt concrete reinforced with synthetic aramid fibers. Studies on aramid fiber reinforced asphalt concrete have shown that the addition of 0.045 wt% aramid fiber to the asphalt mix improves the mix's performance under major pavement stresses such as rutting, fatigue cracking and thermal cracking [14] .

Addition of aramid reinforcement with asphalt concrete will improve the properties of asphalt binder

| **Advantages** | **Potential Drawbacks** |
|---|---|
| Resistance to Cracking, rutting | Cost effectiveness not proven\ varies |
| Increases mixed strength ans stability | |
| High tensile strength | Extra care to avoid non uniform fiber |
| High fatigue life | |
| Crack growth resistance and fracture toughness [14] | Generally needs other ingredients in formulation |

Polypropylene fiber can also used with aramid fiber in asphalt concrete to bring out the best properties.

Research studies show that asphalt reinforced with polypropylene fibers provides better adhesion and acts as a dispersant. Aramid fibers and asphalt concrete, on the other hand, give the mixture a three-dimensional reinforcing network. In this study, 0.05% fiber was incorporated into the mix per ton of asphalt-concrete mix. The results showed less permanent strain buildup in the fiber reinforced compound than in the reference compound. The fiber-modified blends showed 15% and 30% increases in modulus at 25°C. These results are certainly related to improved rutting resistance. Intermediate temperature fracture toughness was also tested by semicircular bending test. The area under the stress-strain curve is 30% larger for the fiber-reinforced asphalt mixture, indicating increased resistance to crack propagation and energy absorption due to fracture [14].

Individually the aramid fibers with asphalt concrete usually shows better results than asphalt concrete with polypropylene fibers the but best results can obtained from combination of these two fibers.

**Steel Fiber**

Steel fibers can be used to support the stresses generated in the surface layer of the pavement. Steel fibers in asphalt concrete improve the static properties and electrical conductivity of the mixture. Steel fiber reinforced asphalt concrete can also provide excellent resilience to minimize cracking and maximum resilience to withstand heavy loads.

Some advantages and drawbacks of steel fiber reinforced asphalt concrete are

| **Advantages** | **Potential Drawbacks** |
| --- | --- |
| Self-healing properties | Poor distribution in mixture |
| Increase low temperature cracking resistance [14]. | Doesn't have relative influence on the particle loss resistance |
| Increase durability | |
| Cost less | |

Previous research results show that fiber length has a positive impact on properties. No reinforcing effect was observed when the fiber length was 6 mm or less and the fiber diameter was 0.01 mm or less. Hooked-end or twisted fibers had no significant effect in improving the toughness of the steel fiber/asphalt mixture. On the other hand, a twisted steel fiber with a length of 30 mm and a diameter of 0.3 mm showed the best toughness improvement of 89.5%. [14]

Short, large-diameter steel fibers have better strength-enhancing capabilities than long, small-diameter fibers. Research studies have shown the effect of length and diameter on high-density asphalt concrete. Fibers are subjected to shear, tensile and impact loads during the mixing process [20]. Large diameter fibers showed less length shortening. Clustering occurs when long fibers ($\geq$ 7 mm, 0.41% clusters) are used instead of short fibers ($\approx$ 2.5 mm, 0.35% clusters) . The cluster fraction also affects the porosity of steel-fiber reinforced asphalt concrete. A high percentage of clustering leads to high porosity, which affects resistance to particle loss. [14].

## Coconut Fiber / Coir

Coconut fibers which is also known as coir, has become an alternative option to replace synthetic or non-renewable materials. Because it is considered an environmentally friendly renewable resource as it is an eco-friendly recycled waste.

These fibers are also relatively impermeable, making them less susceptible to damage from salt water. Previous studies have reported that the most common application of these fibers is in SMA blends, where the fibers should retain the binder within the blend and prevent leakage. In this study, 0.3 wt% coir coir was added to the asphalt mixture. This increased the stability and unit weight value of the mixture and decreased the flow index and air entrainment. Another study showed that 0.52% 15mm coil with 5.72% binder content gave good stability and volumetric properties to asphalt concrete. [14,11]

Some advantages and Drawbacks of coconut fiber reinforced asphalt concrete are:

| Advantages | Potential Drawbacks |
|---|---|
| Prevent drain-down during production. | Excess of fiber could reduce the contact between the aggregate [14,11] |
| 100% natural and ecological recycle. | |

## Carbon fiber

Carbon fiber can be added to asphalt composites using wet or dry processes. The wet process modifies the asphalt binder by adding carbon nanofibers (CNF). The dry process refers to incorporating micro and macro carbon fibers into the mixture. Research studies have shown that homogeneous CNF dispersions improve the viscoelastic and fatigue properties of his CNF-modified asphalt binders.

Some advantages and drawbacks of carbon fiber reinforced asphalt concrete are:

| Advantages | Potential Drawbacks |
|---|---|
| High strength and modulus | Carbon fiber expensive |
| High Thermal Stability | Loses fiber from mix |

| | |
|---|---|
| Increase thermal conductivity of asphalt | Fiber prone to clustering (disturbance in homogeneous distribution ) |
| Higher stiffness | |
| Improve fatigue and permanent deformation | |

According to previous research Carbon fiber content greater than 0.3% by weight of asphalt concrete increases the stability, reduces the flow number and increases the void content and also nanofibers absorb part of the binder leading to an increase in the content of voids in the mixture [14]. The addition of 0.4 % nanofiber by weight of asphalt concrete results in higher resistance to permanent deformation, resilient modulus, and fatigue life and moisture susceptibility can be improved by adding 1% microfibers by weight of mixture.

Another study shows result associated with 12-mm long carbon fibers, incorporating them into the asphalt concrete by using the dry method with 1% fibers increases the flexural strength by 12.1% and the toughness value by 65.5% of the asphalt concrete. [14]

## Cellulose Fiber

Cellulose fibers are natural plant fibers. Cellulose fibers and wool in asphalt-concrete mixtures reduce the drainage properties of bitumen [11] and prevent asphalt mixtures from cracking at low temperatures is inconclusive. These fibers are not strong in tension, but it is absorbent and holds asphalt, therefore it is well-suited to reducing draindown in open-graded mixes but not for reinforcing dense graded concrete. [12].

Advantages and drawbacks of cellulose fiber reinforced asphalt concrete are:

| Advantages | Potential Drawbacks |
|---|---|
| Stabilizes binder in open and gap-graded stone matrix asphalt (SMA) mixture [14] | Low strength and modulus |

**Glass Fiber**

Fiberglass is a synthetic fiber that combines many very fine glass fibres. Research studies have shown that the highest stability and flow values were found at 0.2% glass fiber by weight of the blend.

Some advantages and Drawbacks of glass fiber reinforced asphalt concrete are:

| Advantages | Potential Drawbacks |
|---|---|
| High Elastic recovery | Brittle |
| High strength and modulus | Fiber may break when the cross each other |
| Melts at elevated temperature | May break during mixing and compaction |
| Higher residual stress capacity | |
| Increase Tensile failure strain [11,14] | |

A previous research was done [24] with 20-mm-long fiberglass to the Stone Matrix Asphalt. The results showed that the elongation set and elastic modulus were improved with the addition of less than 0.3% glass fiber. And here are the fatigue life results for glass fiber reinforced asphalt concrete:

| Glass fiber % | Increased fatigue life % |
|---|---|
| 0.1% | 28.2% |
| 0.2% | 37.2% |
| 0.3% | 44.4 % |

Other research paper shows that addition of 0.1% glass fibers and 0.3% polypropylene fibers in porous asphalt concrete results 65% increase in the tensile strength [11, 14].

## Comparison

From the above theoretical analysis it is obvious that different kind of fibers are available to improve properties of asphalt epoxy mixture. Among these fibers to find which one will be more appropriate to prevent failure in pavement is our ultimate research goal. In this case a comparison among these fiber can help to speculate the possibilities.

| | |
|---|---|
| Asbestos fiber | Asbestos shows some properties similar with polyester fiber, aramid fiber and carbon fiber. Because of some health hazard problem asbestos can replaced with these fiber. And as pavements are exposed to normal atmosphere asbestos fiber won't be efficient because of degradation in presence of moisture. |
| Polyester fiber | Although polyester fiber shows some incredible properties but the extra cost because of excess asphalt requirement is an important issue. From the cost effective view natural fiber like coconut fiber, cellulose fiber can make an impact. |
| Nylon fiber | This synthetic fiber is better than natural fiber as they degrade less than natural fiber. |
| Aramid fiber | Aramid fiber shows some special properties like rutting resistance and higher fatigue life but costing and manufacturing difficulties makes it less worthy. Nylon fiber, steel bar, glass fiber can be used instead. |
| Steel bar | At low temperature this type fiber shows better properties than other fibers like aramid or cellulose. |
| Coconut | Natural fiber has degradation problem where synthetic fiber are more stable during weathering. |
| Carbon fiber | Carbon nano fibers are expensive then nylon and aramid fiber and inclined to clustering. |
| Cellulose fiber | This type of fiber shows low strength where carbon fiber or steel bar shows high strength but cellulose fiber are comparatively cost effective |
| Glass fiber | This fiber require better handling and attention during mixing due to breakage problem where we can use nylon fiber or steel bar without these consideration. |

## Conclusion

In this work, failures of traditional asphalt pavements are addressed. Role of epoxy in asphalt pavements are discussed. Curing kinetics of epoxies are described. Optimum epoxy content in asphalt composite mix is shown through experimental data analysis. Effect of different fiber reinforcement to epoxy asphalt composite are mentioned and advantages and disadvantages of different fiber addition is described. More work is required to improve the composite because it plays a vital role in our everyday life.

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