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Rheological and mechanistic characteristics of Bone Glue modified asphalt binders

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HIGHLIGHTS

- Mixing and compaction temperatures were only slightly increased for Bone Glue modified asphalts.
- $G^*/\mathrm{Sin}\,\delta$ and creep compliance of Bone Glue modified asphalt binder were significantly increased.
- Shear fatigue results exhibited substantial increase in fatigue life of Bone Glue modified asphalts.

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ABSTRACT

Polymer modified asphalts are being used frequently in almost every part of the world, especially in developed countries. Higher initial cost of polymer modified asphalts in terms of material, energy, processing, and construction, limits its use in developing countries and in parts of developed countries. A viable and more adaptive option will be a cheaper modifier, bearing low cost of modification and exhibiting improvement in mechanistic and performance characteristics of asphalt binder. This study provides a viable option in terms of Bone Glue modified asphalt binders. Two types of asphalts were modified with varying amount of Bone Glue. Rheological and mechanistic characteristics of neat, control and Bone Glue modified were determined and analyzed. The viscosity results showed that the mixing and compaction temperatures were not significantly changed as compared to the neat one. On the other hand, complex shear modulus, shear fatigue, and creep compliance of the modified binders showed significant improvements relative to the neat and control asphalts. This implies that the Bone Glue modification will not only reduce the initial cost, but will also improve the long-term performance characteristics of pavement.

1. Introduction

Asphalt modification with synthetic and natural polymer is not a new concept in this industry as one can find traces of modification back in 1843 [1]. Asphalt modification is a common practice since last three decades throughout the United States of America (USA). In 1930's, many projects of asphalt modification were underway in Europe [2]. Latin America used synthetic rubber (neoprene) in 1950's [3]. During 1970's European contractor preferred to afford the initial cost instead of bearing the maintenance cost [2]. The disadvantage of higher initial cost of polymer-modified asphalt, limited its use in USA. However, with the invention of advanced polymers, USA started to use European technologies [4–6]. A survey conducted in 1997 revealed that 47 out of 50 states of USA will be using polymer modified asphalt in the future and 35 out of those 47 states would use greater amounts [7]. This inclination towards the use of modified asphalt was due to its lower life cycle cost. Various types of polymers have been added to the asphalt in order to improve its rheological and mechanical characteristics. Such polymers are Styrene–Butadiene–Styrene (SBS), Styrene–Butadiene–Rubber (SBR), Ethylene–Vinyle Acetate (EVA), Elvaloy AM, High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), crumb rubber, and so forth. The polymer modified asphalts show greater elastic recovery, a higher softening point, greater viscosity, greater cohesive strength and greater ductility [3,8,9]. It was found that polymer modification improved structural and engineering properties of the binder, which was a result of improvement in rheological characteristics of binder as well as its adhesion capability with the aggregate. Enhancement in these characteristics inevitably enhanced the laboratory performance of hot mix asphalt mixtures such as; fatigue life, resistance to rutting and thermal cracking [9,10]. It is evident from Table 1

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Table 1
A summary of mixing time and temperature, optimum polymer dosage and PGs of PMA binders.

Polymer type	Mixing temperature (°C)	Mixing time (h)	AC5		AC10		Remarks
			Optimum dosage (%)	PG-grade	Optimum dosage (%)	PG-grade	
Neat	–	–	–	52–22	–	58–22	
SBS	177	2	5	76–28	5	82–28	Network thermoplastics
SEBS	177	2	5	76–22	5	82–22	
SBR	177	1/2	3	64–22	3	76–28	
EAM	193	2	1	76–16	2	82–16	Reacting polymer
CRM	177	1/2	10	70–22	10	76–22	Particle modifier

SBS: Styrene–Butadiene–Styrene, SEBS: Styrene–Ethylene/Butylene–Styrene, SBR: Styrene–Butadiene Rubber, EAM: Elvaloy® Ethylene Copolymer Resins, CRM: Crumb Rubber.

[10] that mixing temperatures of different polymers are more than 177 °C. This is a major concern in modification of asphalt, even though the modification improves the mechanistic characteristics of asphalt binder. Focus of this study is to reduce this temperature and bring it to a level where less fuel and energy is consumed having reasonable improvements in mechanistic and rheological characteristics of asphalt binder.

Polymer modified asphalts are being used frequently in almost every part of the world, especially in developed countries. The amount of energy used for the modification and price of the polymer is a big question mark for the contractors. Polymer needs high temperatures (150–210 °C) and extended period of time (60–200 min) to develop a homogenous blend with asphalt. It is not only preparation of polymer-modified asphalt but also whether the polymer-modified asphalts will show sustainable resistance against all possible distresses throughout the lifetime of pavement. Performance of asphalt pavement is the major criteria to establish a judgment about a modification, whether it is successful, viable or not. However, environmental impact of mixing and compaction process, labor health and safety is getting more attention these days. Initial cost of blend, itself is a major concern for contractors. Initial cost is "the only" concern, presently, due to which developing countries do not prefer to use polymer modified asphalts.

Most commonly used asphalt modifier is SBS polymer. Since 2008 the price of SBS dramatically increased due to shortage of styrene–butadiene polymers for the asphalt industry. Asphalt costs approximately $0.6 per kg (in USA), whereas recycled tire rubber costs about $0.3 per kg (in USA). Likewise, polymer may cost more than $1 per kg (e.g., SBS price is around $1.25 per kg). The shortage involved a variety of polymers, including linear and radial SBS polymers, and diblock SBS polymers. The main reason of SBS shortage is in the supply of "raw material" which is "ethylene". Alternatives of SBS are crumb rubber, which requires high temperature and very high shear mixing conditions. Chemical stabilizers are also added in the mixing process, which increase the cost of the material as well. Some other alternatives are SBR latex, EVA and PPA (Polyphosphoric acid). SBR-Latex is not storage stable, EVA is used in warm climates and PPA is merely and extender and is not an alternative [11]. It also requires almost 170–210 °C temperature to blend the rubber in the asphalt along with high shear mixing at 3500 rpm.

In this study, "Bone Glue" (BG), a by-product of food and cattle industry, has been utilized to modify asphalt binder. BG is protein-based glue made from Collagen extracted from animal bones, hides and flesh waste. Collagen is a group of naturally occurring proteins. It is the most abundant protein in animals i.e., up to 25–35% of the whole body protein content [12]. Various types of Collagen exist, however, Collagen I is 90% of the total collagen present in the body. This type of collagen is acquired from skin, organs, bones etc. It must be noted it is extracted from the organic part of the bone, which is environmental hazard [13].

As mentioned above, BG is made from Collagen, which is adhesive in nature. This characteristic of the material invoked us to believe that it will enhance the adhesive characteristics of asphalt binder as well. Bone Glue is manufactured from bones, skin and paunch waste of animals. Major sources of this waste are either slaughter houses or domestic daily waste. Russ and Pittroff [14] mentioned that specific weight index (mass of accumulated waste divided by mass of saleable product) with respect to type of animal is as follows: Cows 0.56, Pigs 0.2, Calf 0.87 and Sheep 0.1. This waste consists of portions of slaughtered animal that cannot be sold as meat or used in meat-products. Such waste includes bones, tendons, skin, and contents of the gastro-intestinal tract, blood and internal organs [15]. Eleven percent of pork carcasses, 15% of beef carcasses and 16% of lamb carcasses are bone [15]. Average solid waste generation from bovine slaughter house is 275 kg/ton of total live weight killed (TLWK) which is equivalent to 27.5% of the animal weight. In case of goat and sheep slaughter house, average waste generation from pig slaughtering is 2.3 kg/head equivalent to 4% of animal weight [15,16]. The Bone Glue has following characteristics which provide us the basis to select this as a modifier for asphalt binders:

(1) BG is cost effective as compare to conventional polymers.
(2) BG is environment friendly in two ways:
    (a) BG is made from waste material especially from dangerous organic waste, which could be an environmental hazard if not used. Use of BG in pavement industry will utilize the hazardous waste to be consumed during preparation of BG.
    (b) BGA will provide the opportunity to mix and compact the Hot Mixed Asphalt (HMA) mixture at lower temperatures.
(3) BG consumes less energy to blend in asphalt. Further research can refine this procedure in a more effective and energy conservation process.

If Bone Glue is manufactured in abundance to utilize in this industry, major part of the bone waste can be recycled and neutralized this way. It is easily available in developing countries; however the production of this product is very limited due to its limited use; commonly used in local furniture industry. If this product is encouraged, the price can be reduced as well, which will inevitably reduce the initial cost. Presently, it is about $0.8–$1.9 per kg as per manufacturer in Pakistan. Which can be further reduced if purchased in bulk as in tons. A survey of this industry, conducted by the researchers in July 2013 revealed that approximately 20 Factories are currently producing this product all over Pakistan. The limited number of producers is due to replacement of Bone Glue with synthetic glue, because Bone Glue is classified as old type of glue. Advent of synthetic glue also played its role in limiting the use of Bone Glue. It is expected that when the demand will increase, the supply will also increase, which will