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Study on the optimum rice husk ash content added in asphalt binder and its modification with bio-oil

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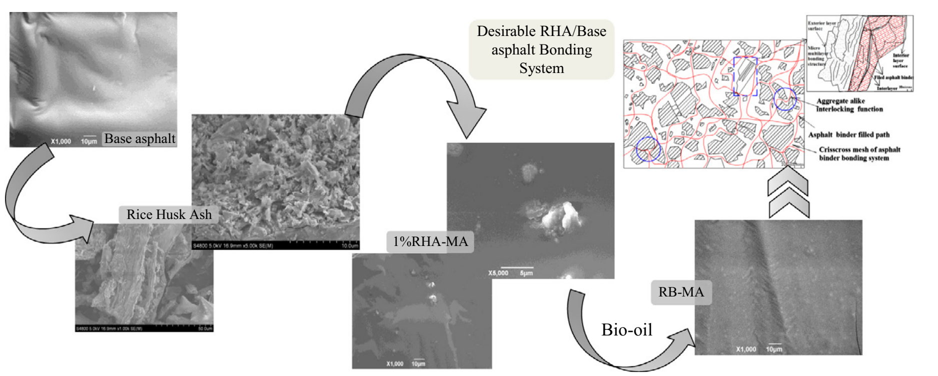
HIGHLIGHTS

- Rice husk ash was used as modifier to improve high temperature properties of asphalt.
- 1% and 7% were confirmed as the optimum content and upper limit for rice husk ash.
- Bio-oil improved the low temperature and fatigue property of RHA modified asphalt.
- 1% rice husk ash/20% bio-oil exhibited optimal asphalt modification effect.
- The ideal bonding system was established by cooperation of rice husk ash and bio-oil.

GRAPHICAL ABSTRACT



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ABSTRACT

By-products and waste materials have become the main cause of environment contamination. In this study, Rice Husk Ash (RHA) was used as modifier to improve the high temperature property of asphalt binder. Bio-oil (BO) was selected as viscosity reducer to enhance the low-temperature and anti-fatigue properties of RHA Modified Asphalt (RHA-MA). Physical and rheological indexes were measured to determine the optimal RHA and BO content. The Scanning Electron Micrographs (SEM) and Energy Dispersive Spectrometer (EDS) analysis were adopted to reveal the modification mechanism of RHA and BO. Results show that RHA-MA possessed desirable high-temperature but unsatisfactory low-temperature performance compared with base asphalt and Limestone Filler Mixed Asphalt (LA). However, asphalt binder with 1% RHA and 20% BO (RB-MA) obtained ductility (15 °C) nearly 50% higher and loss modulus approximately 20% lower than those of RHA-MA. Meanwhile, the softening point is 4.2 °C more and $G^*/\sin\delta$ at all temperatures is higher than those of BO Modified Asphalt (BA). Furthermore, SEM observation illustrates that BO is able to reduce RHA agglomeration and increase the uniformity of RHA-MA mix system, contributing greatly to the excellent comprehensive performance of RB-MA. Consequently, the joint modification of base asphalt with RHA and BO could obtain desirable high temperature, low temperature and anti-fatigue performance. Therefore, it is likely that the development of RB-MA could be helpful to make conventional asphalt qualified for complex service ambient, as well as improve the recycling rate of agricultural waste to reduce environmental pollution and reduce the life cycle cost of asphalt pavement.

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1. Introduction

Rice is a fundamental source of food consumption. Due to the large demand of rice in the world market, as detailed in Table 1 [1], hundreds million tons of rice paddy are consumed yearly [2] and large quantity of rice husks are produced without proper recycling. The most prevalent way in developing countries in East and Southeast Asia is to burn rice husks directly in the filed or dump them into rivers during the farming process, causing great environmental contamination [3].

In recent years, researchers made great efforts into the utilization of RHA as supplementary building materials to decrease the pollution effect and overall construction cost. For example, RHA was used as a stabilizing agent for unstable soil treatment [4–7], as well as a supplementary cementing material for local (Egypt) construction industry [8]. As Wei [9] reported, the durability of sisal fiber reinforced cement could be enhanced by incorporating with RHA. The pozzolanic activities of RHA containing highly reactive silica was confirmed in lime-RHA or Portland-RHA cements [10] and fresh/ hardened high-performance concretes [11]. Meanwhile, the water cement ratio and RHA particle size range were also believed to affect the engineering performance of RHA-OPC system [12,13]. Furthermore, large amount of studies focused on the engineering performance comparison of cement-based composites incorporated with fly ash, silica fume and RHA, such as the shrinkage [14], compressive strength [15], self-compatibility [15], porosity and corrosion resistance [16], as well as the controlled low strength [17]. Nevertheless, it is reported that there should be a limitation of 30% (RHA replacement ratio) in the RHA-cement system [18].

To date, the functions and mechanism of RHA in Portland cement system have been well studied. Research about application in asphalt binder and asphalt concrete, however, is relatively limited. In Hot Mixed Asphalt Concrete (HMA), 50% RHA together with 50% lime stone filler were reported to efficiently improve the Marshall stability of asphalt concrete [19]. In order to study the working mechanism of RHA in asphalt binder, silane coupling agent modified nano-silica and RHA modified asphalt were investigated from the view of comprehensive performance and interface micro-structure between aggregate and asphalt, illustrating that the RHA modification effect was undesirable [20]. Besides, no chemical reactions were found between the biomass ashes (RHA and wood sawdust ash) and asphalt, and the low temperature properties of biomass ash modified asphalt was not satisfactory [21]. Apparently, previous studies are mainly focused on the high temperature and aging properties of RHA modified asphalt. However, the complicated asphalt pavement service condition demands both excellent high temperature and low temperature performance of asphalt used in the mixture. Therefore, this study aims at seeking a proper viscosity reducer compatible with RHA-MA to improve low temperature and anti-cracking properties, as well as maintain high temperature performance qualified for pavement service.

Researchers used bio-oil as alternative source of asphalt and investigated the performance of bio-binder in recent years to face the crisis of the increasingly exhausted asphalt resources. It has been reported that the bio-oil (produced from waste wood) could slightly enhance the tensile strength of asphalt mixture [22], significantly improve the low temperature anti-cracking properties [23,24]. Performance comparison of four different bio-oils (produced from Corn Stover, Miscanthus Pellet, Swine Manure and Wood Pellet) modified asphalt indicated that Wood Pellet modified asphalt had the most desirable low-temperature and rheological properties, but undesirable aging susceptibility [25]. In conclusion, bio-oils could remarkably reduce viscosity and enhance low temperature performance of asphalt binder. It seems feasible to use RHA and bio-oil as composite modifier to combine the outstanding high temperature property of RHA-MA and the excellent low temperature property of BA to obtain modified asphalt with excellent comprehensive performance.

The physical properties test (penetration, softening point and ductility test), rotational viscosity test and Dynamic Shear Rheometer (DSR) were utilized to characterize the modification effect and determine the optimal RHA and bio-oil content. Scanning Electronic Microscopy (SEM) and Energy Dispersive Spectrometer (EDS) were utilized to analyze the modification mechanism of RHA and bio-oil. The application of RHA and bio-oil is supposed to provide an environmental friendly way to prepare modified asphalt with excellent comprehensive performance with less petroleum resource consumption and lower engineering cost, as well as reduce the environment contamination caused by agricultural by-products and waste materials.

Table 1
World Rice Trade. January/December Year, Thousand Metric Tons [2].

TY exports	2012/13	2013/14	2014/15	2015/16	2016/17 Jun	2016/17 Jul
Argentina	526	494	310	480	600	600
Australia	460	404	323	180	230	200
Brazil	830	852	895	700	800	800
Burma	1163	1688	1735	1650	1750	1750
Cambodia	1075	1000	1150	900	1050	1050
China	447	393	262	350	300	300
Egypt	700	600	250	200	250	200
European Union	203	284	251	270	260	260
Guyana	346	502	536	540	540	540
India	10,480	11,588	11,046	9000	8500	8500
Pakistan	4126	3700	4000	4500	4250	4250
Paraguay	365	380	371	480	470	470
Thailand	6722	10,969	9779	9800	9000	9000
Uruguay	939	957	718	850	840	840
Vietnam	6700	6325	6606	6900	7000	7000
Others	1116	1081	1095	1091	1117	1100
Subtotal	36,198	41,217	39,327	37,891	36,957	36,860
United States	3295	2998	3472	3450	3600	3650
World Total	39,493	44,215	42,799	41,341	40,557	40,510

TY = Trade Year. Note about dates: 2015/16 is calendar year 2016, 2014/15 is calendar year 2015, and so on.