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Rutting and fatigue performance of asphalt mixtures containing amorphous carbon as filler and binder modifier

Asghar Habibnejad Korayem [a,*], Hasan Ziari [b], Mojtaba Hajiloo [a], Ali Moniri [a]

[a] School of Civil Engineering, Iran University of Science and Technology, Tehran, Iran
[b] Asphalt and Bitumen Research Center (ABRC), School of Civil Engineering, Iran University of Science and Technology (IUST), Tehran, Iran

HIGHLIGHTS

- Amorphous carbon (AC) powder as filler material improved rutting performance of HMA.
- Using AC powder as bitumen modifier enhanced rutting resistance of binder and HMA.
- AC powder as a bitumen additive is recommended to withstand fatigue cracking of HMA.

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ABSTRACT

In this research amorphous carbon (AC) powder, a waste by-product from paraffin production, was used as a bitumen additive and filler material in asphalt mixtures to investigate its influence on rutting and fatigue behavior of asphalt binder and mixtures. For this purpose, multiple stress creep recovery and time sweep tests were conducted on asphalt binders; dynamic creep, Hamburg wheel track and four point bending beam fatigue tests were carried out as asphalt mixture tests to evaluate fatigue and rutting behavior of asphalt binders and mixtures. Results revealed that replacing up to 50% of filler material by AC powder improved the rutting performance and did not have substantial negative effect on fatigue resistance of asphalt mixtures. Using AC powder as bitumen modifier enhanced rutting resistance of both asphalt binders and their corresponding mixtures substantially. However, in spite of enhancing the rutting resistance and fatigue life at low strain levels, the use of more than 5% AC powder as a bitumen additive impaired the fatigue resistance of asphalt mixtures when exposed to high strain levels. From the results of this study to enhance rutting and fatigue performance of asphalt mixtures incorporation of 50% AC powder as filler material by weight of total filler, and 5% AC powder as bitumen additive is recommended.

1. Introduction

Fatigue and rutting are of the most occurring and major deteriorations of asphalt pavements [1–3]. Fatigue cracking is known as the interconnected cracks in asphalt pavements caused by repetitive loading [4]. Three main parameters affecting fatigue cracking are traffic loading, environmental factors and pavement structure [5]. Rutting is known as a depression or groove worn into a pavement surface caused by accumulation of the permanent deformation in asphalt layers [6–10]. Rutting, which occurs mostly at the early years of asphalt pavement service, is mainly due to the excessive deformation of the asphalt surface course when loaded at high temperatures [11,12]. Aggregate gradation and angularity, maximum nominal aggregate size, bitumen stiffness and bitumen content are the most asphalt mixture components affecting rutting performance [1,13]. Mineral fillers and bituminous mastics are the most fundamental parts of asphalt mixtures, and many behaviors of asphalt mixtures are affected by them. A large proportion of total surface are of mineral aggregates in asphalt mixtures is taken by filler material. [14]. Hence, a substantial interfacial interaction exists between filler and bitumen which greatly affects the performance of asphalt mixtures [14]. Therefore, filler material plays a critical role in asphalt mixture quality, and the performance of asphalt mixtures could be influenced by changing the type of filler as it affects mixtures stiffness and mastic cohesion [15–17]. Many researchers have investigated the effect of filler type on the functional properties of asphalt mixture and mastics. It is indicated that partial replacement of filler material by limestone dust or Portland cement substantially improves rutting resistance of asphalt

* Corresponding author.
E-mail address: ahkorayem@iust.ac.ir (A. Habibnejad Korayem).

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mixtures [18–20]. Moreover, enhancement of the fatigue resistance of asphalt mixtures is reported when 2% of total filler is replaced by hydrated lime [20]. There were also many attempts to use waste and by-product powders as filler in asphalt mixtures. For example, coal powder and ash was utilized as filler material in asphalt mixtures and its effects on the fatigue performance of asphalt mixture was investigated and compared to those of mixtures containing limestone powder, zeolite powder and ordinary Portland cement [21]. It was found that the use of coal waste powder, particularly its ash, leads to enhancement in the fatigue behavior of hot mixed asphalt (HMA) compared to that of mixtures containing limestone, zeolite and Portland cement [21]. Low-temperature durability and fatigue performance of HMA containing cement kiln dust as filler material was investigated in another study by Modarres et al. [22]. Better resistance against freeze–thaw cycles and higher fatigue life was reported for the mixtures containing cement kiln dust as filler [22]. Rutting resistance of HMA containing the green liquor dregs and biomass fly ash from the paper industry as filler material was investigated by Pasandín et al. [23]. It was concluded that the mixtures containing dreg fillers had better rutting resistance than control mixtures. However, replacing fly ash filler impaired rutting resistance of HMA [23]. Many other studies have acknowledged that the filler particle size, shape, texture, porosity and mineral composition have significant effects on rutting and fatigue properties of asphalt mixtures [24–31].

Alongside fillers, bitumen is another crucial ingredient in asphalt mixtures. Modifying bitumen with various additives have long been on the agenda of asphalt industry researchers [10,32]. One of the bitumen modifiers that recently have been considered by researchers is powders and nano-scaled particles. Adding micro and nano-scaled particles into bitumen have shown enhancement in its different features due to the high surface area of nanomaterial, stiffening effect of additive particles to bitumen and chemical reaction of some nanoparticles with bitumen or its ingredients [33–36]. Sobolev et al. [37] evaluated the rheological properties of bitumen modified with fly ash. They concluded that addition of fly ash improved the rutting factor and raised the high performance grade of the binder. Nejad et al. [35] studied the influence of nano-silicon dioxide (SiO_2), nano-titanium dioxide (TiO_2), and nano-calcium carbonate ($CaCO_3$) on the low and intermediate temperature range of asphalt binders. The results indicated that using aforementioned nanomaterial have adverse influence on glass transition and fatigue performance of asphalt binders due to their stiffening and hardening effect on asphalt binders. Ziari et al. [38] showed that carbon nanotubes (CNTs) improved the rutting performance of asphalt binders due to the physicochemical interaction between CNTs and asphalt binder. Nano lime modified bitumen was investigated by Kavusi and Barghabani [39]. It was shown that adding hydrated lime nano particles as additive to bitumen improved fatigue performance of base bitumen.

Amorphous Carbon (AC) powder is made of refining by-product of solid and liquid paraffin production factory that does not have any application in industry [40]. Therefore, finding a safe solution for reuse of this material can benefit the environment by preventing dispose of this by-product material, as well as less use of natural resources. One of the best ideas of reusing this by-product is to use them as additive in pavement layers and asphalt concrete.

Our previous study [40] showed that using the AC material as filler in asphalt mixture and additive in bitumen substantially improved the moisture resistance of asphalt mixture due to its hydrophobic nature, low surface energy and surface roughness. However, other properties of asphalt binder and mixture containing AC are unknown and need to be investigated. In this study the AC powder was used as filler in asphalt mixture and as additive in asphalt binder to evaluate the rutting and fatigue performance of the modified bitumen and asphalt mixture. Results indicated that using up to 50% of AC powder as filler and 5% as bitumen additive enhanced rutting and fatigue performance of asphalt mixtures. The outcomes of this research pave the way for future application of AC powder as additive in asphalt binders and mixtures.

2. Materials

Limestone aggregates were obtained from Tello quarry, Tehran, Iran. The gradation of aggregates is depicted in Fig. 1. In this figure, the upper and lower limits are chosen based on ASTM D3515. Other quality tests of aggregates used in this study are shown in Table 1. 60/70 penetration grade bitumen which is frequently used to produce asphalt mixtures was provided from Pasargad Oil Company. Properties of asphalt binder used in this study are listed in Table 2.

The amorphous carbon which is a useless waste from paraffin production was used as an additive in asphalt mixtures. The physical properties of this additive are listed in Table 3. Fig. 2(a) shows the visual shape of amorphous carbon and Fig. 2(b) and (c) present the optical microscopy shape of amorphous carbon passed from sieve number 200 and 400, respectively. Moreover, the size and angularity of carbon powder and limestone filler can be observed in Fig. 3(a)–(f). This powder has higher roughness and specific surface area than limestone powder. Hydrophobicity is another indication of this powder. Therefore when AC is used as filler in asphalt mixtures, it forms a rough surface on aggregates and improves the adhesion of bitumen to aggregates [40]. More information about chemical properties of the AC powder and its discussion can be found in our previous research [40].

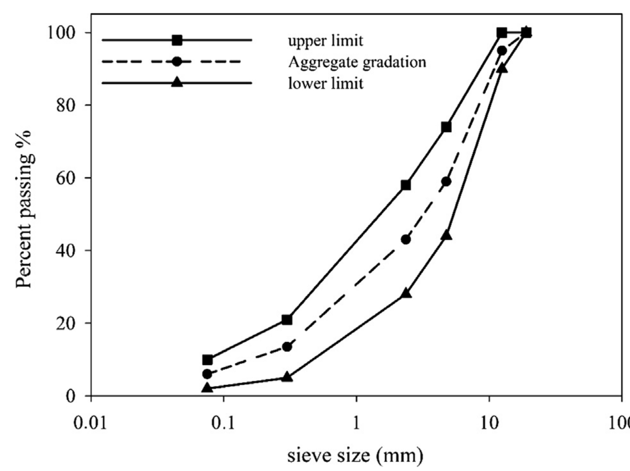

Fig. 1. Gradation of aggregates of asphalt specimens.

Table 1
Properties of celsius aggregates (CA).

Physical properties	CA
Specific gravity (fine agg.) (g/cm^3)	2.65
Water absorption (%)	0.7
Specific gravity (coarse agg.) (g/cm^3)	2.64
Los Angeles abrasion (%)	19.3

Table 2
Properties of 60/70 penetration grade binder used in this study.

Test	Standard test	Result
Viscosity Test at 135 °C (cSt)	ASTM D2170	364
Penetration Test (dm)	ASTM D5	95
Ductility Test (cm)	ASTM D113	100
Softening point (°C)	ASTM D36	45.6
Flash point (°C)	ASTM D92	290
Specific Gravity (g/cm^3)	ASTM D70	1.015

Table 3
Physical properties of amorphous carbon.

Physical properties	AC
Color	Dark black
Particle size (μm)	10–70
Specific gravity (g/cm^3)	0.92
Specific surface area (m^2/g)	4.76