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Effect of coal waste powder in hot mix asphalt compared to conventional fillers: mix mechanical properties and environmental impacts

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A B S T R A C T

The demand for using waste has significantly increased because of the depletion and limitation of the natural resources. Coal waste is a by-product that produced in coal washing plants. The accumulation of coal waste in the nature causes several ecological and environmental problems. The main objective of this study was to investigate the applicability of coal waste powder and its produced ash as fillers in hot mix asphalt (HMA) compared to the conventional fillers. In this study, other conventional fillers including limestone powder, zeolite powder and ordinary Portland cement were also used. Experimental tests have been performed to evaluate the mechanical properties of HMA containing different fillers. Accordingly, Marshall stability, indirect tensile strength, moisture sensitivity, resilient modulus and fatigue tests were conducted. Environmental impact of using coal waste filler in HMA was evaluated by using toxicity characteristic leaching procedure (TCLP). The results of the mechanical tests indicated that the use of coal waste powder and especially its ash improved the performance of HMA compared to limestone and zeolite. Furthermore, the use of the coal waste ash resulted in nearly similar mechanical properties to ordinary Portland cement. The heavy metal leachates in TCLP test showed to a large extent similar results for different studied samples which all were below the regulation levels. Finally, it can be concluded that, the use of coal waste powder as filler in HMA not only leads to desired mechanical properties, but also reduces the volume of the pollutants waste in environment.

1. Introduction

One of the most important roles of the filler in asphalt mix is prolonging the lifespan of the pavement and increasing its resistance against water penetration. Besides, using filler in asphalt mix increases the bearing strength, impact resistance, bitumen viscosity and finally decreases its brittleness (Yan et al., 2013). Fillers vary by concerning gradation, particle shape, combination of mineral material and physical and chemical properties. Hence, choosing the appropriate filler for asphalt mixtures is prominently important (Muniandy and Aburkaba, 2011). Due to the decrease in natural resources, the increase in road construction activities, reducing energy consumption as well as considerations for environmental aspects, utilizing waste materials has turned into an important issue during the recent years. Hence, several researchers have tried to study the possibility of using waste material in pavements construction (Clay et al., 2007; Pérez-Martínez et al., 2014). In recent studies the use of the waste materials such as recycled lime waste, phosphate waste filler, municipal solid waste incineration ash, ceramic waste material, cement kiln dust and rice husk ash have been studied and most of these materials were reported as beneficial fillers in asphalt mixes (Modarres and Rahmanzadeh, 2014; Taha and Al-Rawas, 2002).

Coal has an important role in world energy supply, but its production process has adverse environmental effects through generation of waste materials. Coarse waste products are derived from coal mining and fine wastes are produced by the preparation

Abbreviations: AMD, Acid Mine Drainage; CP, Cement Powder; CWA, Coal Waste Ash; CWP, Coal Waste Powder; HMA, Hot Mix Asphalt; ITS, Indirect Tensile Strength; LOI, Loss On Ignition; LS, Limestone; MQ, Marshall Quotient; M_r, Resilient Modulus; MSR, Marshall Stability Ratio; N_f, Fatigue Life; TCLP, Toxicity Characteristic Leaching Procedure; TSR, Tensile Strength Ratio; ZP, Zeolite Powder.

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process. Coal preparation includes physical processes that upgrade the quality of coal by regulating its size and reducing the mineral matter quantity. The main operation units are classified by screening, cleaning, crushing, and separation. The most common method used for coal preparation is gravity concentration (Jig machine) for coarse and intermediate size coal and floatation is applied to fine size coal (Laskowski, 2001). One of the most important emerging issues caused by the dumping of coal waste is the danger to the environment. Generally, coal waste dumps should be regarded as a serious long-term source of soil and water contamination (Szczepanska and Twardowska, 1999). The problem of pollution in coal mines is commonly caused by pyrite oxidation. When the pyrite and the iron-bearing minerals are exposed to water, air or both of them, they go through rapid oxidation which leads to the creation of acid mine drainage (AMD). The pollution caused by AMD is considered as the most important source of water pollution near the mines which includes ferrous sulfate and other materials (Cánovas et al., 2007). AMD is considered as one of the major sources of water pollution. AMD with a low pH includes a significant amount of iron, SO_4^{-2}, and varying amounts of poisonous heavy metals such as As and Cu (Doulati Ardejani et al., 2010). In fact, coal waste can change both of surface and underground water composition, especially by releasing toxic elements (Chudy et al., 2014).

Alborz Markazi coal washing plant which is located in the northern part of Iran is one of the coal washing plants that produces several tons of waste materials. The waste dump with 10 m height and approximate weight of 1.5 Mt, covers an area of about 2 ha around the plant area. The findings of a study proved the occurrence of pyrite oxidation within the coal waste dumps in this area (Shahhoseiny et al., 2013).

Several experiments have been carried out by using coal waste in the construction industry. Coal waste was used as a replacement for cement and aggregate in concrete products and as a stabilizer in pavement granular layers which showed satisfactory performance results. Additionally, coal waste has been used as aggregate in HMA (Modarres and Rahmanzadeh, 2014). According to the experimental findings the use of coal waste aggregate in HMA caused a decrease in mixture durability (Kandhal, 1992).

Apart from the mechanical properties the environmental impacts of incorporating waste materials in asphalt and other pavement's layers is an important issue that must be considered. The fact that these layers are constantly in direct contact with surface and underground waters increases the risk of water pollution through leaching the hazardous materials such as heavy metals into underground water resources. The small amounts of heavy metals can be necessary for health, but too much may cause acute or chronic toxicity (Halim et al., 2003). The constant leaching of heavy metals from coal mining and coal plants leads to bioaccumulation in plants and animals, creating the danger of toxicity. Heavy metals toxicity can result in damaged or reduced mental and central nervous function, lower energy levels and damage to blood composition, lungs, kidneys, liver and other vital organs (Disfani et al., 2012; Zha et al., 2013).

The leaching test is the primary and most widely used indicator of chemical stability and hence, the potential environmental effects of the treated layer (Ilyas et al., 2014). Leaching can be defined as the process by which a component of waste is removed mechanically or chemically into solution from the solidified matrix by the passage of the solvent such as water (Ling and Poon, 2014).

According to literature one of the main leaching procedure that has been utilized to analyze the potential of heavy metal leachability from the stabilized layers is toxicity characteristic leaching procedure (TCLP) test (Xue et al., 2009; Tsang et al., 2013). TCLP is designed to determine the mobility of both organic and inorganic compounds present in liquid, solid as well as multiphasic samples. To determine the potential of specific wastes to leach dangerous concentrations of toxic chemicals into groundwater, the US environmental protection agency developed a protocol known as TCLP (USEPA, 1992).

TCLP has been commonly used as a regulatory tool to determine whether or not a waste can be classified as a hazardous waste. During an early laboratory study TCLP was used to assess the leachate from a cement stabilized waste. It was found that both the pH level and heavy metal concentration was stabilized after 18 h. However, some modifications were suggested to improve the efficiency of procedure (Xue et al., 2009).

In another study the TCLP test was utilized to examine the effect of the various leaching parameters on the leaching of lead (Pb) and cadmium (Cd) from cementitious wastes. It was realized that the metal concentration in leachate drastically reduced by increasing the pH level. There was no considerable change in the metal amount in leachate for leaching durations of more than 18 h. Furthermore, the liquid to solid ratio of 20 was realized as the optimum quantity that achieved the highest metal amount in leachate (Halim et al., 2003).

Zha et al. (2013) studied the effects of cyclic drying and wetting on engineering properties of lead and zinc contaminated soils stabilized with fly ash. Test results showed that the leaching characteristics of heavy metal ions of stabilized contaminated soils were significantly improved with the increase of fly ash content. They indicated that the TCLP concentration increased with the increase of the times of drying and wetting cycles.

Xue et al. (2009) studied the effects of municipal solid incineration ash in stone mastic asphalt mixture. They performed TCLP test for controlling the leachate quality. Based on the presented report, the cumulative metal leaching capacity increased with the increase of leaching times and the decrease of pH of leachant. Furthermore, the heavy metal leachates in TCLP tests had great positive correlation with their initial concentration in waste. But Ni was an exception that lower initial concentration led to higher cumulative leaching rate.

The aim of this work is to investigate the possibility of using the coal waste powder (CWP) and its ash (CWA) as replacement of the conventional limestone (LS) powder in hot mix asphalt (HMA). In this regard two other pozzolanic fillers including the ordinary Portland cement (CP) and zeolite powder (ZP) were also considered. The experimental study focused on both HMA mechanical properties and environmental impacts of studied fillers especially the CWP. In fact the experimental study performed in this research had two objectives. First, mixtures were designed and analyzed by HMA mechanical tests. Second, designed mixtures were analyzed to reach the requirement of environmental impact by TCLP test.

2. Materials

The materials used to prepare the HMA specimens in this study were high quality aggregates, 85/100 pen grade bitumen and 5 types of fillers. The technical properties of these materials are presented in the following subsections.

2.1. Aggregate

The gradation of LS aggregates that used for HMA samples preparation and the standard specification based on Iran highway asphalt paving code, (2011) are presented in Table 1. According to this table a 0–25 mm gradation was used and the amount of filler for all studied mix proportions was fixed to 7%.