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Investigation of waste ceramic tile additive in hot mix asphalt using fuzzy logic approach

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HIGHLIGHTS

- Effects of WCA replacement on performance properties of HMA are evaluated.
- Asphalt specimens with WCA could improve some performance characteristics of HMA.
- Marshall test results of specimens were successfully estimated by fuzzy logic model.
- Paper contributes to the encouragement of WCA re-use in HMA environmentally friendly.
- Using WCA in HMA is a one of the effective practices of sustainable environment.

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ABSTRACT

The aim of this paper is to explore the effects of waste ceramic tile additives on performance properties of asphalt mixtures. Within this context varied rates of waste ceramic tile aggregates (WCA) were used as aggregate for preparation and experiments for hot mix asphalt (HMA) specimens by using Marshall Design Method. Static and Dynamic Creep Tests were applied to the new 30 specimens prepared according to optimum bitumen contents (OBC) and all experimental results were evaluated. Additionally, effects of two important variables (WCA ratio and bitumen ratio) on Marshall Stability (MS), on air void content (AVC) and on voids of filled with asphalt cement (VFA) were modelled. It was concluded that, since specimens with HMA have good enough mechanical conditions according to Turkish Highway Construction Specifications in HMA for wearing course, up to 30% of natural aggregates can be replaced by WCA. By using WCA, country resource will be used effectively within the context of sustainable environment. Besides experimental results were evaluated and predicted with high accuracy by using fuzzy logic (FL) approach. Thanks to the FL model, we could predict values which are wanted to have knowledge about materials characterization with less specimens and less tests without spending much time and workforce.

1. Introduction

The HMA, which is used in highway construction, is composed of bitumen and aggregate. These materials are well-known for their high production cost. Reduction of quality aggregate and bitumen resources day by day, has led researchers to investigate on different sources to conserve material. The issue of environmental pollution caused by industrial development has led reusing and recycling of the waste materials to be highly considered. Therefore, reuse in HMA would reduce the environmental impact, prevent the pollution as well as it would be an alternative for the natural resources.

Recently, several studies are conducted for using of wastes in Portland cement concrete and HMA mixtures [1–4]. Van de Ven et. al., examined the partial replacement of industrial sand as filler and waste ceramic (CW) obtained from electrical insulators as coarse aggregate in HMA. In the study, the modified specimens showed similar results to control specimens in Indirect Tensile Strength (ITS) and Marshall Stability tests, whereas there was an increase in compressive strength values [5].

Torkittikul and Chaipanich studied the feasibility of using ceramic tile waste and fly ash as fine aggregate to produce mortar and Portland cement concrete. From the result it was seen that the workability is reduced by the usage of WCA. Also, the compressive strength in the fly ash concrete increased with increasing waste ceramic tile content [6]. Pacheco-Torgal and Jalali investigated the feasibility of using WCA as aggregates (as filler, fine and coarse)

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in traditional concrete. Results showed that replacement of WCA increased the compressive strength value of concrete. And also performance properties of concrete mixtures with WCA improved against to control concrete mixtures concerning oxygen permeability, capillary water absorption and chloride diffusion which makes the concrete structures more durable [7].

Silvestre et al., analyzed the possibility of using WCA in HMA for binder and wearing courses. It was observed that moisture susceptibility, AVC, OBC and resistance of plastic deformation were increased with increasing the waste ratio, although compressive strength and MS were decreased. Up to 30%, by weight, addition of RCA into HMA showed suitable results according to Spanish Standards, the wearing course and binder course with RCA were considered to be suitable for medium-low traffic volume roads [8,9].

The production of ceramic tile in factories in Turkey leads to approximately 8% of waste material. This rate is over 13% in the factories engaged in first quality production. Ceramic tile production in Bilecik-Eskişehir-Kütahya regions make 43.2% of total ceramic tile production in Turkey [10]. Approximately 100,000 tons of ceramic waste is produced in this region every year. The wastes formed in the region can be converted to the aggregates at a low cost. The aggregate obtained from the waste materials in the region, cover a significant portion of the annual aggregate amount used in road construction in Eskişehir [11]. In some studies, the effect of waste materials on performance properties of concrete is modelled by FLA. [12–18]. Özgan modelled changing ductility values of bitumen in various temperatures and waiting times by fuzzy logic approach (FLA). By using this model, results showed that ductility values depend on the temperature and waiting time were able to be predicted with 96% accuracy [19]. Morova et al., investigated the effect of bitumen amount on strength of HMA by FLA. Developed model was able to predict with 97.9% accuracy [20]. Sayın and Tanyıldızı examined the stiffness of the HMA by using fuzzy logic and Shell method. It was observed that, the obtained results from fuzzy logic model have close results in comparison with calculated values by using Shell method [21]. WC is produced at a tremendous rate and there exist lack of natural resource for road construction all over the world. However, there are only a few studies about WCA recycling in HMA. Besides paper is the first study about that static and dynamic creep stiffness and strain behavior of WCA in HMA is investigated and Marshall test results of WCA in HMA are modelled by FLA. Within this context varied rates of WCA, by weight, were used as aggregate for preparation of experiments for HMA specimens with Marshall Design Method. Static and Dynamic Creep Tests were applied to the new 30 specimens prepared according to OBC and all experimental results were evaluated. Finally, the effect of two important variables (WCA ratio and bitumen ratio) on MS, AVC and VFA were modelled by FLA. Predicted results obtained from fuzzy logic model were compared with experimental results.

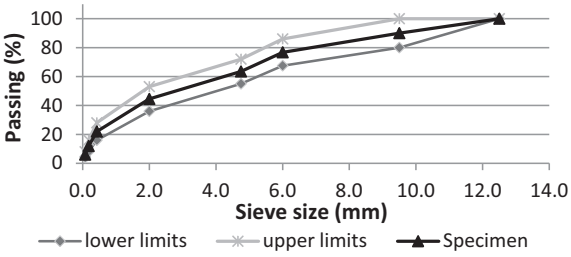

Fig. 2. Type II. aggregate grading curve for wearing course.

2. Materials

50/70 penetration bitumen was used in experiments. Bitumen experiments are conducted and their compliance with specifications is explored. Natural aggregates and WCA were used in the mixtures. WCA was obtained from plant waste disposal areas in Eskisehir (Fig. 1). These wastes are ceramic tiles fractured ones while glazing, packaging, transportation or these are caused by manufacturing defects. According to chemical analysis of WCA used in the experiments has small amount of glaze coat (approximately 5.5%, by weight).

The aggregate grading curve chosen as Type II wearing course obtained from Turkish Highway Construction Specifications [22] is shown in Fig. 2. Specimen grade values were obtained by taking average values of the upper and lower limit values.

3. Methods and experimental study

Significant experiments were applied to natural and WCA and bitumen which were used in the mixtures. Physical properties and the required specifications related to bitumen and aggregates are shown in Tables 1 and 2.

WCA were crumbled by a jaw crusher in laboratory and prepared according to required Type II gradation as shown in Fig. 3.

Marshall Mix Design Method is used for HMA specimen's preparation. Five different aggregate mixtures are prepared according to the Type II gradation, including different ratios (0%, 10%, 20%, 30% and 40%, by weight) of WCA. Seven different percentage of bitumen (3.5%, 4%, 4.5%, 5%, 5.5%, 6%, and 6.5%, by weight) were added to the mixtures. Three for each specimen's combination were prepared; in total 105 HMA specimens (ceramic percentage: 5 type, bitumen percentage: 7 type and 3 for each specimen, respectively 5 * 7 * 3 = 105) were prepared. Marshall Stability & Flow Test was

Fig. 1. Waste ceramic tile obtained from disposal area of Toprak Ceramic Factory.