Asphalt mixture performance and testing

Improvement of Resistance to Moisture-Induced Damage of Activated Carbon Modified Hot Mix Asphalt Using Hydrated Lime

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Abstract

Due to the change in traffic and climatic conditions, the traditional bituminous binders are insufficient to resist various deformations in flexible pavements. For this purpose, various additives are used in bitumen or mixture modification. The materials obtained from various biomasses are tried to be used as bitumen additives because of the high cost of commercial additives and also for the utilization of waste materials. Although active carbon obtained from various biomasses have a positive effect on the various performance parameters of bituminous binders and mixtures, they generally affect the against resistance moisture-induced damage negatively. In the study, activated carbon obtained from pulp residue and vinasse was used in bitumen modification in 3 different ratios (5%, 10% and 15%). Mixtures prepared with pure bitumen and modified bitumen were subjected to resistance test against moisture-induced damage in accordance with AASHTO T 283 standard. The results of the experiments showed that the resistance to moisture-induced damage of the mixtures containing activated carbon was lower than the pure mixture. Hydrate lime was added to the mixture as filler (2% by weight of the mixture) in order to eliminate this negativity. Hydrated lime-containing mixtures were tested with the same procedures. The obtained results showed that the resistance to moisture-induced damage increased significantly with the use of hydrated lime as filler in the mixtures prepared with both pure binder and activated carbon modified bitumen.

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1. INTRODUCTION

Hot mix asphalts (HMAs) used in wearing, binder and/or base courses are produced by heating and mixing bitumen and aggregate in order to carry traffic loads and protect the other layers in the flexible pavement from the negative effects of environmental conditions. HMAs have a composite structure consisting of aggregate, bituminous binder and air void distributed in the mixture. Properties of HMAs depend on the material; different binder-aggregate combinations, aggregate gradations and modification techniques.

In flexible pavements, due to increasing traffic load and climatic conditions, deteriorations such as rutting, stripping, cracking and undulations occur. Additives are used to delay these deteriorations, reduce maintenance and replacement requirements and improve pavement performance. In many countries, modified bitumen or mixtures are obtained by adding various additives to bituminous binders or mixtures [1-2]. Polymers are widely used additives in the production of modified bitumen [2]. When cost and environmental approaches are considered, products obtained from waste of various natural materials are also used as additives. Natural waste materials can be used in pavements as bitumen additive after they are subjected to inter-processes such as pyrolysis [3].
In the master's thesis conducted by Seyrek [4], the effects of active carbon obtained from agricultural wastes of marc and vinasse were investigated as a modifier on the rheological properties of bitumen binders and mechanical properties of hot mix asphalt. For this purpose, active carbon, using vinasse generated at distillation step in the alcohol production from molasses together with grape marc, was used. The active carbon was added to neat bitumen (B 160/220) in 3 different ratios (5%, 10% and 15% of neat binder). It was obtained from mixture tests that Marshall stability, stiffness, resistance to fatigue cracking and permanent deformation of the mixtures were increased with active carbon modified bitumen usage. Also, the use of activated carbon in bitumen modification adversely affects the resistance against moisture-induced damage [4].

Another method employed for increasing the durability of HMAs is the modification of the mixture. In this method, the additives are directly added into the mixture. The added additives are mostly used as filler material. Materials such as lime, carbon black, fly ash are additives which can be used as fillers [5]. Hydrated lime is employed to limit moisture-induced damage of the HMAs [6]. Moreover, it stiffens the mastic better than normal mineral filler, this can be noticed only above room temperature, which influences the mechanical properties of the asphalt mixture [7]. It is revealed that the most effective hydrated lime ratio was 2% of aggregate weight [8].

It has been determined that HMAs' various performance properties positively affect resistance to moisture-induced damage by using active carbon obtained from marc and vinasse agricultural wastes as bitumen additives [4]. In this study, the effect of using 2% hydrated lime as a mixture additive, instead of filler, with active carbon obtained from marc and vinasse agricultural wastes as a bitumen additive was investigated in terms of the resistance to moisture damage of bituminous hot mixtures.

2. MATERIALS AND METHOD

Concentrated vinasse was obtained from Eskişehir Sugar Factory Alcohol Production Facilities, and marc from Elazığ Sivrice Eskibağlar Wine Factory. Washing, drying, grinding and sieving pretreatments of marc were performed in a previous study [9]. A 50 mesh particle size calibrated sample is homogenously mixed in a blender with a weighing ratio of 1:2 at 22000 rpm for 3 minutes of rapid stirring. After 6 hours, the samples were taken into 85 ml porcelain crucible and placed in an oven at 100°C. Pyrolysis was carried out for 120 minutes in a 600°C oven with 300 ml / min nitrogen gas. For pyrolysis, the samples were placed in the oven at room temperature and nitrogen gas was introduced for 10 min. The oven was started to heat, reaching a temperature of 600°C in 15 minutes. After the treatment, the samples taken from the oven were cooled in a vacuum desiccator. The pyrolysis products were milled and sieved through a 200 mesh (<0.075 mm) sieve. The samples were extracted with water by shaking at 200 rpm for 120 minutes at room temperature (23-27 ° C), water / (pyrolysis product) ratio of 10. The solid samples remaining from the extraction were mixed with 2M HCl solution (10 times the pyrolysis product obtained) with agitation for 12 hours. The solid separated from the liquid by filtration through Gooch crucible was subjected to washing to neutrality and washed with pure water until the $AgCl_3$ of the samples did not form $AgCl_3$ solution and the final used solid activated carbon was dried at 100°C for 12 hours [9]. The properties of activated carbon used in the study are shown in Table 1 and SEM images are shown in Figure 1.

Table 1. Properties of activated carbon obtained [9]

(Pyrolysis conditions :S/C =2, Pyrolysis temperature : 600°C, Pyrolysis time : 120 minute , Acid stabilization : 2N HCl, s Liquid / solid ratio = 10, Drying Temperature : 100°C).

Property	Value
Visible density (g/cm^3)	0.7814
Actual density (g/cm^3)	1.7223
BET surface area (Micro + Meso)((m^2/g)	498.4
Micropore surface area (m^2/g)	379.1
Mesopore surface area (m^2/g)	119.3
Langmuir surface area (m^2/g)	658.2
[1]Pore volume (Micro+Meso)(cm^3/g)	0.2463
Micropore volume (cm^3/g)	0.1757
Mesopore volume (cm^3/g)	0.0706
[2] Diameter of pore (Å)	22.7
Particle size [Weighted average (D[4,3]), μm]	19.489
Particle size [d(0.1), μm]	4.398
Particle size [d(0.5), μm]	16.820
Particle size [d(0.9), μm]	38.417
Ash (%)	5.1
Volatile matter (%)	28.70
Fixed carbon (%)	66.20

Elemental_analysis

C	H	N	S	O
63.5	2.38	3.70	0.60	24.72

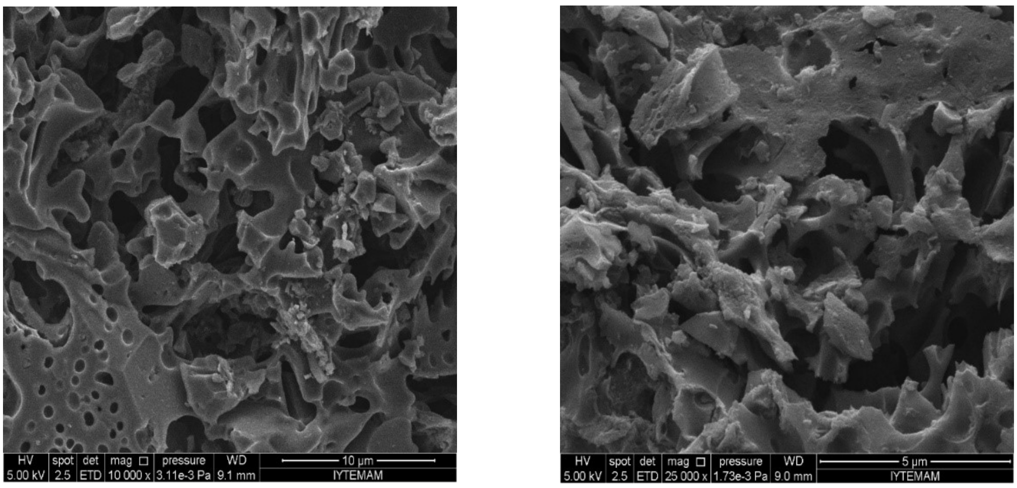

Figure 1: SEM images of the obtained activated carbon

(Pyrolysis conditions :S/C =2, Pyrolysis temperature : 600°C, Pyrolysis time : 120 minute , Acid stabilization : 2N HCl, s Liquid / solid ratio = 10, Drying Temperature : 100°C).

In this study, B 160/220 (EN 12591) neat binder obtained from Batman TÜPRAŞ refinery was used as the main binder. Modified bitumen were obtained by the addition of activated carbon by the pyrolysis (carbonization) process in the rates of 5%, 10%, and 15% per bitumen weight to the bitumen. The mixing temperature was selected as 180°C during the preparation of modified bitumen. Neat bitumen and the bitumen modified with the selected ratios of additive were stirred at 1000 rpm rate of rotation for 1 hour (Figure 2).

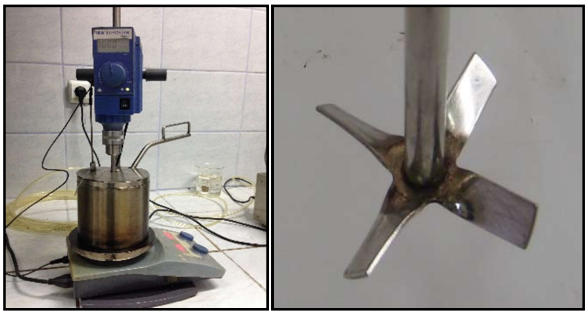

Figure 2: Modified bitumen mixer and mixing cap

Penetration test in accordance with EN 1426, softening point in accordance with EN 1427, and rotational viscosity in accordance with ASTM D4402 standard were performed on the binders [10-12]. The binder test devices used in the study are shown in Figure 3.

Figure 3: Penetration, softening point and rotational viscosity test devices used in the study

Resistances of the mixtures prepared with a pure binder and 3 active carbon modified bitumen including 3 different ratios (5%, 10% and 15%) activated carbon by weight of bituminous binder against moisture-induced damage were determined based on AASHTO T283 standard [13]. For this purpose, 6 samples were prepared for each binder with 7 ± 0.5% air void. Samples prepared with 4.9% bitumen content were kept in an oven at 60°C for 16 hours and then were exposed to short-term aging process under compaction temperature for 2 hours. Compacted samples were left for cooling under ambient temperature and the next day volumetric properties of the mixtures were determined. 6 samples were divided into 2 groups where each group had similar void rates. 3 samples (1st group) were kept in 25°C water for 2 hours and were broken by applying 50.8 mm/min load on a plane perpendicular to the compaction surface. Samples in the other group were vacuumed and saturated with water to fill the voids at a rate of 70-80%. Samples with a different void rate than 7 ± 0.5% and whose voids were filled more than 80% were canceled and new samples were prepared to replace these. Samples saturated with water were covered with the stretch film to prevent the change in saturation level. Samples covered with stretch film were exposed to the conditioning process. In this process, samples were initially stored in -18°C freezer for 16 hours, and then in 60°C' water for 24 hours. Later on, the samples were kept in 25°C water at least for 2 hours and were broken under 50.8 mm/min load, similar to unconditioned samples. Based on the maximum level of load at failure, the indirect tensile strength (ITS) in units of kPa is calculated by the following equation:

$$ITS = 2 * F / \pi * L * D \quad (1)$$

where F is the peak value of the applied vertical load (kN); L is the mean thickness of the test specimen (m); and D is the specimen diameter (m).

3. RESULTS

3.1. Binder Test Results

Conventional binder test results were given in Fig. 4 and Fig. 5. As it is seen from Fig. 4 and Fig 5. consistency, softening point and viscosity of binders were increased with raised activated carbon content. The mixing and compaction temperatures were determined for binders by using the 170 ± 20 and 280 ± 30 cP viscosity values, respectively. Viscosity values were increased due to the use of activated carbon, which in turn increased the mixing and compaction temperatures.

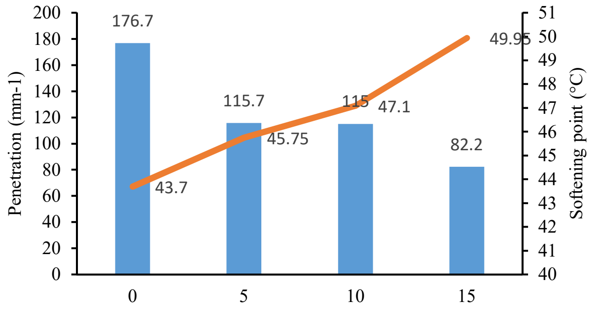

Figure 4: Penetration and softening point values of binders

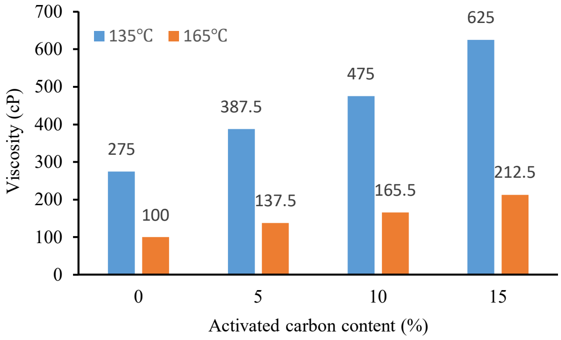

Figure 5: Viscosity values of binders

3.2. Aggregate test results

Limestone aggregate was used for the asphalt mixtures. The properties of the aggregate are given in Table 2. A crushed coarse and fine aggregate with a maximum size of 19 mm was selected for a dense graded asphalt mixture. The gradation of the aggregate mixtures is given in Fig. 6 [14].

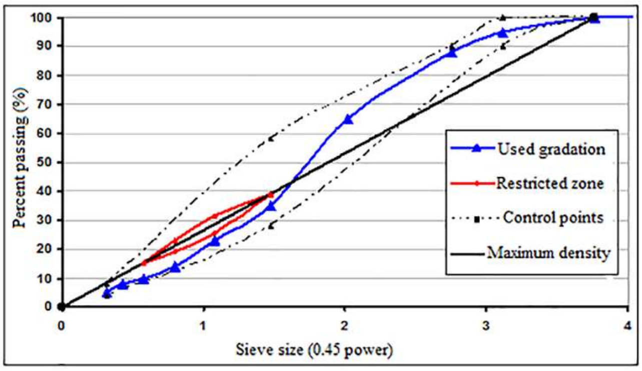

Figure 6: Combined aggregate gradation

Table 2. Physical properties of the aggregate [14]

Properties	Standard	Specification limits	Value
Abrasion loss (%) (Los Angeles)	ASTM D 131	Max 30	29.2
Abrasion loss (%) (Micro deval)	ASTM D 6928	Max 15	17.4
Frost action (%) (with Na_2SO_4)	ASTM C 88	Max 18	16.7
Methylene blue (gr/kg)	ASTM C 837	Max 1.5	0.5

3.3. Moisture-induced damage test results

In the master thesis study conducted by Seyrek [4], it was determined that the mixtures prepared with activated carbon modified bitumen were less resistant to moisture-induced damage than the pure mixture. In this study, the resistance of the mixtures against moisture-induced damage was attempted to be increased by using hydrated lime. Therefore, pure bitumen and 3 activated carbon modified binders and 2% hydrated lime were used as fillers and mixture samples were prepared in the same bitumen contents. Mixture samples containing hydrated lime were also tested for resistance to moisture-induced damage according to AASHTO T 283 standard. The test configuration and the fractured samples are shown in Figure 7.

Figure 7: ITS test configuration and fractured samples

Indirect tensile strength values of unconditioned and conditioned mixtures are shown in Fig. 8. As shown in Figure 8, ITS values were decreased due to conditioning in both with- and without lime treated mixtures. It was determined that 15% activated carbon modified mixture had the highest value in lime-free and unconditioned mixtures, and the pure mixture was obtained in conditioned samples. In lime-containing and unconditioned mixtures, it was determined that pure and 5% active carbon-containing mixtures had the highest value, and after conditioning the pure mixture had the highest value. The lowest value in all mixtures was observed in mixtures containing 10% activated carbon modified bitumen.

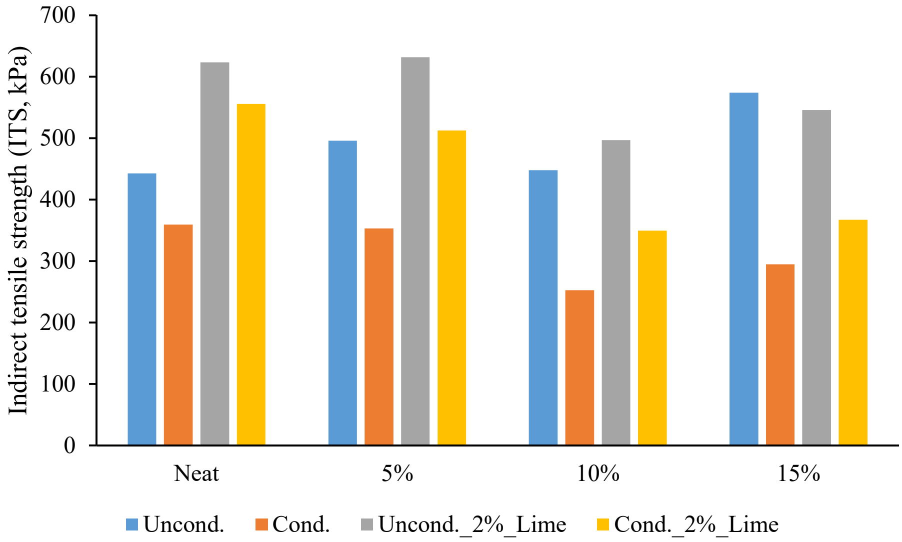

Figure 8: Indirect tensile strength values of mixtures

Tensile strength ratio (TSR) values of mixtures were given in Fig. 9. TSR values decreased with increasing active carbon content in both with- and without lime treated mixtures. The highest TSR values were obtained by pure mixture and the lowest values observed in mixtures prepared with 15% activated carbon modified bitumen. By using 2% lime as filler in the pure mixture, TSR value increased by 9.83%. TSR values increased by 13.97%, 24.59% and 30.71%, respectively, by using 2% lime as fillers in mixtures prepared with %5, % 10 and% 15 active carbon modified bitumen. In lime-free mixtures, 70% TSR value was obtained by pure and prepared with 5% activated carbon modified bitumen used mixtures. In lime-treated mixtures, it was determined that the mixtures prepared with pure, 5% and 10% activated carbon modified bitumen exceeded 70% TSR value. It was found that lime use was more effective in activated carbon modified bitumen containing mixtures although pure mixture had the highest TSR value.

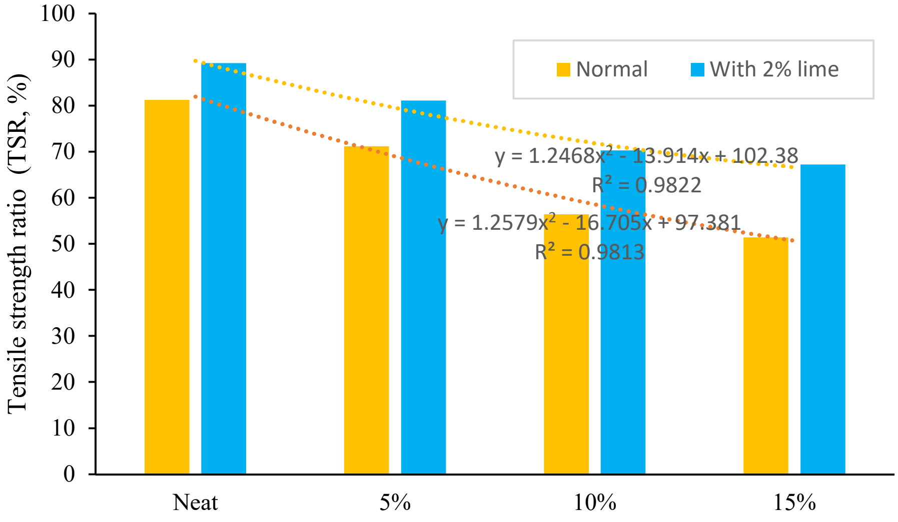

Figure 9: Tensile strength ratios of mixtures

4. CONCLUSIONS

In this study, HMA samples were prepared with pure bitumen and modified bitumen containing 3 different active carbon ratio (5%, 10% and 15%) by weight of bitumen. Mixture samples also were prepared using 2% hydrated lime as fillers with the same binders. The prepared mixtures were tested for resistance to moisture-induced damage according to AASHTO T 283 standard. Half of the prepared samples were conditioned by applying a freeze-thaw period. All samples were broken at 50.8 mm/min loading rate and indirect tensile strength values were determined. Tensile strength ratio values were determined by the ratio of ITS values of conditioned samples to ITS values of unconditioned samples. It has been determined that the resistance against HMAs moisture-induced damage was reduced by using activated carbon in bitumen modification in lime-free mixtures. When 2% hydrated lime was used as filler, all mixtures have increased resistance to moisture damage. In mixtures containing 2% hydrated lime as filler, TSR values were reduced by using activated carbon in bitumen modification. By using 2% lime in pure mixture, TSR value increased by 9.83%. TSR values increased by 13.97%, 24.59% and 30.71%, respectively, by using 2% active carbon modified bitumen. Therefore, it was concluded that the use of hydrated lime as fillers in mixtures using activated carbon in bitumen modification was more effective.

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