Chapter 24

Improving Microwave Heating Characteristic of Asphalt Binder by Using Fly Ash

Mert Atakan and Kürşat Yıldız

Abstract

Previous studies have indicated that asphalt can heal itself, if it is allowed to rest enough. Current research on self-healing is focused on induction and microwave heating methods which provides with adding metallic fibers to asphalt mixture. However, any study about usage of fly ash to improve microwave heating of asphalt binder is not encountered. Because utilization rate of fly ash that is an environmental pollutant is 25% in the world, is required to find new field to use it. This chapter studies usability of fly ash as a microwave absorber in order to accelerate microwave heating of asphalt binder. In order to achieve this, specimens that contain fly ash at different ratio were prepared and microwave heating rate of these specimens were tested. These tests revealed that fly ash can accelerate microwave heating of bitumen, so it has a potential to improve self-healing of asphalt. The study also showed that below 20% of fly ash ratio by bitumen weight may not be enough to provide self-healing.

Keywords: microwave heating, self-healing, asphalt binder, fly ash, heating rate

1. Introduction

Asphalt mixture, composed of aggregate, filler, and asphalt binder, is widely used for pavement construction in the world. The reasons of this choice are that it provides comfortable driving, its initial investment cost is relatively low, it reduces wheel noise, it needs less qualified labor, and it can be repaired fast. However, throughout service life, asphalt pavement exposed many effects such as climate effects, aging of bitumen, and traffic loads. Because of these effects, micro cracks occur and these cracks grow larger and bring about surface cracks, raveling, and potholes at last [1]. Deteriorations are usually repaired using conventional methods such as regional patch, filling the potholes, and rebuilding the pavement. These methods are insufficient due to both high cost and traffic disruption. New methods are needed to extend the service life of the pavement and to make the repair process less costly and faster.

Bazin and Saunier [2] revealed the self-healing phenomenon of asphalt in 1967. They reported that after the loading, asphalt can heal when it is allowed to rest, and temperature of the asphalt plays an important role in self-healing. After that, self-heling of asphalt has become a research focus.

As the bitumen is very viscous material [3], it tends to flow through a micro crack just as capillary flow [4]. Thus, the crack heals as the bitumen fills in it. Little and Bhasin [5] explained the healing mechanism in 2007. They reported, as soon as external load removed, viscoelastic recovery occurs, regardless of the external load is large enough to damage the material or not. On the other hand, if the load is large enough to damage the material, healing occurs immediately after removal of external load. They also explained the difference between viscoelastic recovery and healing; "While the former is due to the rearrangement of molecules within the bulk of the material, the latter is due to the wetting and interdiffusion of material between the two faces of a nano crack to achieve properties of the original material".

The healing process lasts until the material returns to its original state as long as the material is not exposed to the traffic load. Traffic load would make the cracks even worse. Furthermore, the process may last days at the ambient temperature [6]. In practice, however, it is not possible to stop the traffic to provide healing at the ambient temperature [7]. If asphalt concrete is exposed at higher temperature, healing rates are also enhanced [8, 9]. Moreover, a lot of researcher reported that cracks which are seen at winter disappear at summer [10]. In 2011, Garcia [4] reported that increasing the temperature of asphalt mix, increases the healing rates of the asphalt mix and there is a certain temperature and fixed heating time to provide self-healing of asphalt.

Self-healing of asphalt can be accelerated via some methods such as induction heating and microwave heating. Induction heating can heat electrically conductive materials such as metals by electromagnetic waves and adding such materials to asphalt mix makes it electrically conductive. Therefore asphalt mix can be heated by induction heating [7]. Much research on induction heating has been done [7, 10–18]. However, microwave heating has become a research focus recently. In 2013, Gallego and his colleagues [19] revealed microwave heating method and some studies on it has been done until now [15, 16, 19–29]. Different additives were used in asphalt mix to provide self-healing via microwave heating such as carbon nano tubes (CNT) [22], steel slag [21, 23, 29], carbon powder [27], and recycled asphalt pavement (RAP) [20, 28].

Fly ash is a by-product which is generated by combustion of coal at the thermal power station and it is known as a environmental pollutant [30]. Blissett and Rowson [31] estimated that 750 million tons of fly ash is produced annually worldwide and Wang [32] predicted that fly ash utilization rate is about 25%.Therefore, in order to deal with this environmental pollutant, it is necessary to find new fields where fly ash can be used in. In this chapter, fly ash was used as an additive for asphalt binder in order to accelerate microwave heating of asphalt binder, since fly ash is much more affected from microwaves than bitumen or aggregate is.

2. Materials and methods

2.1 Material description

In order to prepare specimens, 50/70 penetration grade bitumen supplied from Kırıkkale oil refinery was used. The fly ash which was mixed with bitumen was supplied from Çayırhan Thermal Power Plant. The fly ash type was chosen randomly by taking into consideration the amount of metal oxides. The chemical composition of the fly ash based on another study is given in **Table 1**. According to same study, blaine fineness of fly ash is 2830 cm^2/g. The microwave oven which is used in the experiment has 800 W output power and 2450 MHz frequency same as any microwave ovens.

Chemical composition of the fly ash (%)			
SiO_2	46.6	Na_2O	1.01
Al_2O_3	12.4	K_2O	2.28
Fe_2O_3	9.74	SO_3	5.52
CaO	14.5	Loss on ignition	1.08
MgO	7.23		

Table 1.
Chemical composition of the fly ash (%) [33].

2.2 Preparation of specimens

In order to prepare specimens, 30 g of bitumen were put in each beaker and fly ash was weighed. Both fly ash and bitumen were heated at 150°C in the drying oven before mixing together them. After that, 150°C bitumen which is in the beaker was put on the heater and hot fly ash was added in it and the bitumen had been stirred with a stick until they mixed homogeneously (**Figure 1**). Finally, they were left to cool for one night.

Fly ash ratio was chosen variable from 2 to 50% by weight of bitumen and they were named from FA2 to FA50. Besides, a control specimen which contains 0% of fly ash was generated. Apart from that, a specimen generated contains 2% of steel wool in order to confirm heating effect of metallic fibers and named SW2 (**Figure 2**).

2.3 Testing of microwave heating characteristic

Microwave heating test was used in order to determine microwave heating rates of different samples. Microwave output power employed 800 W. First, samples were heated for 20 seconds and measured its temperature. As the immersion thermometer works slowly, it waited for 1–2 minutes to read the temperature of specimen. After that, specimen was heated another 20 seconds and it went on six times



Figure 1.
Preparation of the specimens.



Figure 2.
Steel wool used in the specimen.



Figure 3.
Measuring the temperatures of asphalt specimen.

in total to reach 120 seconds. Same experiment was repeated for 40 seconds breaks and 60 seconds breaks, until reach 120 seconds in order to eliminate errors.

While measuring the temperature via the immersion thermometer, the specimen was cooled at the same time. Therefore, the temperatures which were gauged were lesser than it should be. To solve this problem, temperatures were measured quickly with an infrared thermometer and compared with the immersion thermometer (**Figure 3**). According to values obtained from infrared thermometer, measured temperatures enhanced 5%, in order to compensate cooling.

3. Results and discussion

These tests showed that microwave heating rate of bitumen increased as fly ash ratio increase. According to infrared thermometer values, there was a difference between top surface and bottom surface of the bitumen sample at the rate of up

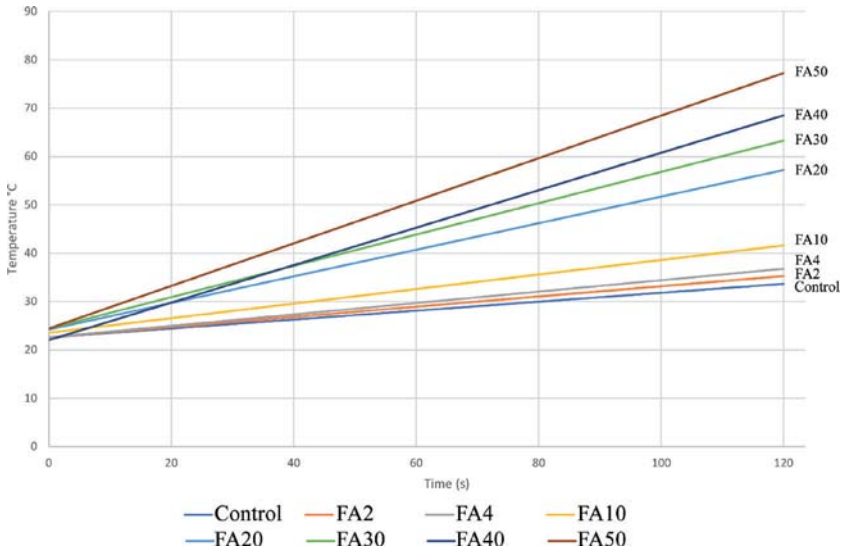


Figure 4.
Microwave heating rate of asphalt binder specimens.

to 30–40%. This means that additives did not mix with bitumen homogeneously; instead they settled at the bottom of the beaker. We faced the same problem with the specimen which contains 2% steel wool. The bottom surface of the specimen reached 90°C in 20 seconds via microwave heating, while top surface barely exceeds the ambient temperature. To get rid of the problem, asphalt mix may be used instead of merely asphalt binder.

Tests indicated that little amount of fly ash such as 2 or 4% is not very effective to improve heating rate of bitumen. Therefore, high amount of fly ash such as from 20 to 50% was used subsequently.

The sample which contains 2% of steel wool reach approximately 90°C at the bottom and 24°C at the top in 20 seconds. When the temperature is balanced, it was around 50°C which is quite higher than the all samples with fly ash.

Garcia [4] reported that below certain temperatures, healing cannot occur because bitumen behaves non-Newtonian fluid. However this certain temperature changes with the type of bitumen and usually healing can start between 30 and 70°C [34]. In our study, 20% and higher fly ash ratio was enough to reach 30°C in 40 seconds and 50% fly ash ratio was enough to exceed 40°C in 40 seconds (**Figure 4**). In order to confirm whether this temperature is sufficient or not to self-heal, further experiments are required such as determining healing index of asphalt mix containing fly ash or comparing the viscosity of asphalt binder containing fly ash.

The effect of the fly ash to mechanic properties of asphalt was not evaluated. However, it is observed that high amount of fly ash may reduce its ductility. According to previous study, high amount of fly ash rate gives rise to a drop at ductility and penetration of the asphalt, whereas its softening point is rising [35].

4. Conclusions and recommendations

In the chapter, contribution of the fly ash to microwave heating of bitumen was researched. A sample with 2% of steel wool was also tested in order to compare the results. From the outcome of our investigation, it is possible to conclude that:

- Fly ash has a potential to enhance microwave heating acceleration of the bitumen.
- Fly ash should be used higher than 20% in order to reach 40°C in a short time. Therefore, it can be used as a filler in asphalt mix rather than a modifier in binder.
- Steel wool, which is used in literature commonly, was also tested at the ratio of 2% and the specimen reached quite high temperature at a short time. Therefore, the next step of our research will be the combination of steel wool and fly ash in the asphalt mix.
- It was seen that the specimens did not mixed completely homogeneously. In order to get rid of this problem, asphalt mix can be used for tests instead of only bitumen.
- The study is important for sustainability because fly ash which is an environmental pollutant and usage of microwave heating which is an efficient way to heat are used.
- Practical application of the method is still a problem and microwave heating method has not been used in practical yet. Despite of practical application costs, the method is promising to extend service life of the asphalt pavement and to reduce maintenance cost.
- Further study of the issue is still required.

Acknowledgements

The authors would like to thank their colleagues Prof. Dr. Salih Yazıcıoğlu and Assoc. Prof. Dr. Osman Şimşek for their contribution in conducting some of the experiments for the research. Besides, the authors also would like to thank to their colleagues Tech. Osman Aydın for his technical assistance.

Author details

Mert Atakan* and Kürşat Yıldız
Faculty of Technology, Department of Civil Engineering, Gazi University, Ankara, Turkey

*Address all correspondence to: mertatakan@gazi.edu.tr

IntechOpen

© 2019 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. CC BY

References

[1] Xu S, García A, Su J, Liu Q, Tabaković A, Schlangen E. Self-healing asphalt review: From idea to practice. Advanced Materials Interfaces. 2018;**5**(17):1-21

[2] Bazin P, Saunier J. Deformability, fatigue and healing properties of asphalt mixes. In: International Conference on the Structural Design of Asphalt Pavements. Ann Arbor, Michigan; 1967. pp. 553-569

[3] Read J, Whiteoak D. The Shell Bitumen Handbook Fifth edition, Exhibit 1008. 2003. p. 463

[4] García Á. Self-healing of open cracks in asphalt mastic. Fuel. 2012;**93**:264-272

[5] Little DN, Bhasin A. Exploring Mechanism of H ealing in Asphalt Mixtures and Quantifying its Impact. 2007. pp. 205-18

[6] Qiu J. Self Healing of Asphalt Mixtures. Delft: Delft University of Technology; 2012

[7] Liu Q, Schlangen E, García Á, van de Ven M. Induction heating of electrically conductive porous asphalt concrete. Construction and Building Materials. 2010;**24**(7):1207-1213

[8] Bonnaure F, Huibers A, Boonders A. A laboratory investigation of the influence of rest periods on the fatigue characteristics of bituminous mixes. Association of Asphalt Paving Technologists. 1982;**51**:104-128

[9] Daniel JS, Kim YR. Laboratory evaluation of fatigue damage and healing of asphalt mixtures. Journal of Materials in Civil Engineering. 2001;**13**(6):434-440

[10] Liu Q, Wu S, Schlangen E. Induction heating of mastic asphalt for crack control. Construction and Building Materials. 2013;**41**:345-351

[11] Lizasoain-Arteaga E, Indacoechea-Vega I, Pascual-Muñoz P, Castro-Fresno D. Environmental impact assessment of induction-healed asphalt mixtures. Journal of Cleaner Production. 2019;**208**:1546-1556

[12] Gómez-Meijide B, Ajam H, Lastra-González P, Garcia A. Effect of air voids content on asphalt self-healing via induction and infrared heating. Construction and Building Materials. 2016;**126**:957-966

[13] García Á, Schlangen E, Van De Ven M, Van Vliet D. Induction heating of mastic containing conductive fibers and fillers. Materials and Structures/Materiaux et Constructions. 2011;**44**(2):499-508

[14] Gómez-Meijide B, Ajam H, Garcia A, Vansteenkiste S. Effect of bitumen properties in the induction healing capacity of asphalt mixes. Construction and Building Materials. 2018;**190**:131-139

[15] Sun Y, Wu S, Liu Q, Hu J, Yuan Y, Ye Q. Snow and ice melting properties of self-healing asphalt mixtures with induction heating and microwave heating. Applied Thermal Engineering. 2018;**129**:871-883

[16] Norambuena-Contreras J, Garcia A. Self-healing of asphalt mixture by microwave and induction heating. Materials & Design. 2016;**106**:404-414

[17] Pamulapati Y, Elseifi MA, Cooper SB, Mohammad LN, Elbagalati O. Evaluation of self-healing of asphalt concrete through induction heating and metallic fibers. Construction and Building Materials. 2017;**146**:66-75

[18] García A, Bueno M, Norambuena-Contreras J, Partl MN. Induction healing of dense asphalt concrete. Construction and Building Materials. 2013;**49**:1-7

[19] Gallego J, Del Val MA, Contreras V, Páez A. Heating asphalt mixtures with microwaves to promote self-healing. Construction and Building Materials. 2013;**42**:1-4

[20] González A, Norambuena-Contreras J, Storey L, Schlangen E. Self-healing properties of recycled asphalt mixtures containing metal waste: An approach through microwave radiation heating. Journal of Environmental Management. 2018;**214**:242-251

[21] Phan TM, Park DW, Le THM. Crack healing performance of hot mix asphalt containing steel slag by microwaves heating. Construction and Building Materials. 2018;**180**:503-511

[22] Li C, Wu S, Chen Z, Tao G, Xiao Y. Improved microwave heating and healing properties of bitumen by using nanometer microwave-absorbers. Construction and Building Materials. 2018;**189**:757-767

[23] Sun YH, Liu QT, Wu SP, Shang F. Microwave heating of steel slag asphalt mixture. Key Engineering Materials. 2014;**599**:193-197

[24] Norambuena-Contreras J, Gonzalez A, Concha JL, Gonzalez-Torre I, Schlangen E. Effect of metallic waste addition on the electrical, thermophysical and microwave crack-healing properties of asphalt mixtures. Construction and Building Materials. 2018;**187**:1039-1050

[25] González A, Valderrama J, Norambuena-Contreras J. Microwave crack healing on conventional and modified asphalt mixtures with different additives: An experimental approach. Road Materials and Pavement Design. 2019;**20**(1):149-162

[26] Tabaković A, O'Prey D, McKenna D, Woodward D. Microwave self-healing technology as airfield porous asphalt friction course repair and maintenance system. Case Studies in Construction Materials. 2019;**10**

[27] Wang Y, Liu Z, Hao P. Investigation on mechanical and microwave heating characteristics of asphalt mastic using activated carbon powder as electro-magnetic absorbing materials. Construction and Building Materials. 2019;**202**:692-703

[28] González A, Norambuena-Contreras J, Storey L, Schlangen E. Effect of RAP and fibers addition on asphalt mixtures with self-healing properties gained by microwave radiation heating. Construction and Building Materials. 2018;**159**:164-174

[29] Li C, Wu S, Chen Z, Tao G, Xiao Y. Enhanced heat release and self-healing properties of steel slag filler based asphalt materials under microwave irradiation. Construction and Building Materials. 2018;**193**:32-41

[30] Ahmaruzzaman M. A review on the utilization of fly ash. Progress in Energy and Combustion Science. 2010;**36**(3):327-363

[31] Blissett RS, Rowson NA. A review of the multi-component utilisation of coal fly ash. Fuel. 2012;**97**:1-23

[32] Wang S. Application of solid ash based catalysts in heterogeneous catalysis. Environmental Science & Technology. 2008;**42**(19):7055-7063

[33] Sevim Ö, Demir İ. Optimization of fly ash particle size distribution for cementitious systems with high compactness. Construction and Building Materials. 2019;**195**:104-114

[34] Grossegger D, Garcia A, Airey G. An approach to determine the physical properties governing the self-healing ability of bitumen. 1st European Road Infrastructure Congress. 2016

[35] Zhang W, Chen C. Experiment study on the rubber and fly ash of modified asphalt. In: ISWREP 2011—Proceedings of 2011 International Symposium on Water Resource and Environmental Protection. Vol. 4. 2011. pp. 2971-2974