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Research Article

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An experimental application on energy harvesting with piezoelectric on asphalt pavements

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Highlights

- Different piezo electric sensors were tested
- These technologies will be widely used in the future, especially in urban roads.
- Flexibility properties of bituminous hot mixtures may be potential in the energy harvesting.

Abstract

With the dramatic increase in the world population, the demand for transportation and, accordingly, energy is also increasing. Clean and renewable energy sources are one of the most important research topics in all countries. The word piezo-electric that, means energy from pressure, is the ability of the material to change an electric field or electric potential as a result of mechanical pressure applied to some materials. This effect is directly related to the change in polarization density inside the material. If the material is not short-circuited, the applied loading and stress creates a voltage in the material. Energy production with materials that provide piezoelectric energy harvesting placed within asphalt pavements is one of the topics that road pavement engineers have been researching in recent years. This study was carried out as a preliminary study. In this study, experiments were made using different sensors to improve energy harvesting from asphalt pavements. The difference of this study from other studies was that different piezoelectric sensors were placed in the asphalt mixture samples and the measurements of the resulting voltages were made. As a result of the experimental study, voltages up to 0.210 V were obtained in the asphalt samples. The obtained results showed that this method is encouraging for energy harvesting and might be the answer for highway transport demand in the future.

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1. Introduction

In recent years, with the climate change, the use of fossil-based energy has been gradually decreasing and clean energy sources are gaining even more importance for the future. In addition, uninterrupted and renewable energy is accepted as one of the most important development indicators all over the world. Energy harvesting from roads is also considered as one of the renewable energy sources and research on the subject continues. From the energy harvesting technologies, two groups of technologies have a great potential for implementation on pavements: one uses solar radiation as an energy source and the other uses the mechanical energy from vehicle loads. Piezoelectric materials are reversible and exhibit a "direct piezoelectric effect" (generating electric potential when stress is applied). Piezoelectric property is the ability of the material to change an electric field or electric potential as a result of mechanical pressure applied to some materials (especially quartz certain crystals). This effect is directly related to the change in polarization density inside the material. If the material is not short-circuited, the applied stress creates a voltage in the material. Piezoelectric energy harvesting from asphalt pavements is considered as a potential clean energy that can convert mechanical energy generated by traffic on

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the road into electrical energy [1]. Millions of vehicles pass over the pavement during its service life, which causes deformation, stress, and vibrations on the pavement. A large amount of mechanical energy is wasted during this process. Conversion of mechanical vibration energy to electrical energy will be a breakthrough for energy saving and emission reduction, as well as one of the key parameters for sustainable transportation infrastructures [2, 3]. Piezoelectric energy harvesting has been studied by many researchers for years. The patent of US20050127677 [4] and US20100045111 A1 [5] relate to systems that make use of piezoelectric transducers on road pavements that produce electrical energy. Zhao et al. [6] reported that the way to harvest mechanical energy from asphalt pavement by piezoelectric generator. Results show that the potential energy in asphalt pavement can be up to 150 kW/h per lane per kilometer. The energy obtained from here is used for road led road safety signs (road signs), pedestrian crossings, traffic signaling lamps, surface lighting, road lighting and so on. can be used in applications [7-9]. Power density versus voltage for various energy harvesting technologies are given in Figure 1.

1.1. Objectives

The aim of this study is to investigate the embedding conditions of piezoelectric sensors in asphalt samples in various ways, to find the optimum positions of the piezoelectric sensors, to determine the electric potential generation performance of different piezoelectric generators under the influence of vibration. For this purpose, experimental set up were made using two different types of piezoelectric sensors (mono and series connected) and evaluation of the results of the energy harvest were made.

2. Materials

2.1. Aggregates

Limestone was used as aggregate, and 0-4 mm, 4-11 mm and 11-22 mm were obtained from Afyonkarahisar KOLSAN AŞ. The aggregates supplied were sieved and washed so that the HMA Type 2 wear layer in the Turkish Highways Technical Specification (HTS) [10] in Table 1 remained between the gradation limits, and then dried. The physical and mechanical properties of the aggregates are given in Table 2.

2.2. Bitumen

B50/70 penetration grade bitumen produced in Aliağa refinery was used as binder. Bitumen was taken from Afyonkarahisar Municipality asphalt construction site. Bitumen properties are given in Table 3.

Table 1. Bituminous hot mix asphalt (HMA) type 2 wearing course gradation.

Sieve Diameter (inch, No)	Sieve Size (mm)	Passing (%)	Specification Limits	
			Min.	Max
1/2"	12,5	100	100	100
3/8"	9,5	90	80	100
No.4	4,75	63,5	55	72
No.10	2,00	44,5	36	53
No.40	0,425	22	16	28
No.80	0,180	12	8	16

Table 2. Aggregate physical and mechanical properties.

Aggregate Tests	Values	Standard
Coarse Aggregate Volume Specific Gravity (>No:4)	2.683	[11]
Coarse Aggregate Apparent Specific Gravity (>No:4)	2.710	
Fine Aggregate Volume Specific Gravity (No:4 – No: 200)	2.671	[12]
Fine Aggregate Apparent Specific Gravity (No:4 – No: 200)	2.699	
Filler Apparent Specific Gravity (<No: 200)	2.738	[13]
Water Absorption (%) (>No:4)	0.4	[11]
Water Absorption (%) (No:4 – No:200)	4.0	[12]
Los Angeles Abrasion Loss (%)	23.1	[14]

Table 3. Properties of 50/70 penetration grade bitumen.

Properties	Values	Standard
Specific Gravity	1.035	[15]
Penetration Degree (25 °C)	52.13	[16]
Softening Point (°C)	46.65	[17]
Brookfield Viscosity at 135 °C (cP)	495.00	[18]
Brookfield Viscosity at 165 °C (cP)	131.00	

2.3. Piezoelectric

Ceramic coated 5 cm and 3 cm diameter brass piezoelectric sensors with a diameter of 2 cm were used as piezoelectric material (Figure 1). The 5 cm diameter of these sensors was used as a mono sensor, and the 3 cm diameter sensors were used in series in HMA mixtures.

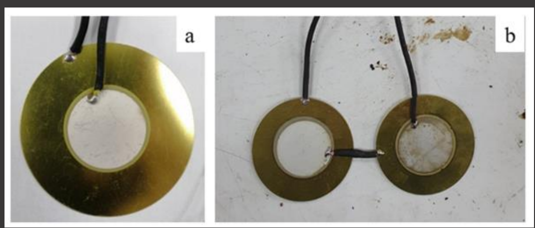

Figure 1. Differently designed piezos and their connections; a) 2 cm diameter ceramic coated 5 cm diameter brass piezo, b) 2 cm ceramic coated 3 cm diameter brass piezos connected in series.

3. Method

3.1. Preparation of Marshall samples

Aggregate mixtures of 1200 grams were prepared in accordance with the gradation in Table 1. Then Marshall samples were produced at 5% bitumen content. Experiments were performed according to ASTM D 1559–89 [19]. Based on the research of Gürer et al. [20], the same mixture was used and the optimum bitumen percentage was used as 5%.

3.2. Experimental arrangements

3.2.1. First Experiment Setup

Two experimental setups were prepared. In the first experimental setup, a sample was produced with a 5 cm diameter brass, 2 cm diameter ceramic surface piezo, and a sample with two three cm diameter brass, 2 cm diameter ceramic surface piezo connected in series. In the sample produced with piezo with a diameter of 5 cm; Before compaction, Marshall samples with a depth of 6.0 - 6.5 cm were poured, then placed on a 0.5 cm deep mastic layer and covered with the remaining mastic material. Before compressing the sample, a cork made of oak bark with a mold inner diameter (approximately 10 cm) was placed on the prepared sample in order to minimize the possibility of damaging the piezo. The unilaterally compressed sample was left to cool (Figure 2). Voltage (V) measurements were carried out with the help of fluke brand multimeter by applying force to the produced samples by hand and with a wooden hammer.

Figure 2. First experimental setup; a) Placing the asphalt mixture into the mold, b) Placing the piezo on the mixture, c) Covering the mixture on which the piezo is placed with mastic, d) placing the cork on the sample before compaction, e) Compaction the sample, f) Sample after compaction.

3.2.2. Second Experiment Setup

In the second experimental setup, while the ceramic surface of the piezo was placed facing the surface corresponding to the bottom of the mold, 3 mm thick plywood and 3 mm cardboard were protected on the back surface to prevent grounding on this surface. In the first of the samples produced with piezo with a diameter of 5 cm; Before compaction, 6.5 cm Marshall sample was poured and placed and covered with remaining material. In the second, after 4.5 cm of mixture was poured, it was covered with the remaining mixture and then compacted. In the sample produced with 3 cm diameter piezo; After pouring a 6.5 cm Marshall sample, it was placed and covered with the remaining mixture and compacted (Figure 3). The properties of the samples produced in different configurations are given in Table 4. While two different piezo of the same size were buried at different depths, it was possible to compare the effect of both depth difference and piezo sizes on voltage generation by embedding two different piezo close to the surface.

Table 4. The properties of the samples produced in different configurations

Sample No	Piezo Depth (cm)	Piezo Diameter (cm)
1	6.5	5
2	4.5	5
3	6.5	3

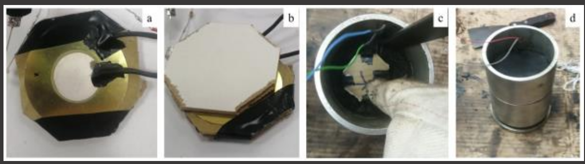

Figure 3. Second experimental setup; a-b) Protection application to the piezos, b) Placing the piezo into the asphalt mixture, c) Making the prepared sample ready for compaction.

Just before the compression phase, protection was provided with a rubber material with a thickness of 1.5 cm suitable for the diameter of the mold in order to prevent the Marshall proctor ram from damaging the sample and to simulate the effect of the wheel load of the automobiles (Figure 4). Voltage measurements were made with a digital fluke brand ® multimeter device by applying force with a modified proctor hummer (Figure 5).

Figure 4. Rubber material

Figure 5. Voltage reading device with multimeter

4. Results

4.1. First experiment setup results

It was observed that the samples produced a maximum of 0.49 V at weak force applied by hand before being removed from the mold (Figure 6). In the force applied with the wooden mallet, it was observed that the led bulb lit with 2 V produced enough light to be observed in a bright environment. The sample with embedded piezo electric sensor connected in series failed during the compression phase due to their disconnection (Figure. 7). As a result of the damage to the piezo connections, a second experimental setup was prepared to protect the piezo and connections (Figure 3). The stress values of the sample decreased after the demolding process.

Figure 6. Measuring voltage of the embedded piezoelectric sensors

Figure 7. Damaged series-connected piezo electric sensor after the Marshall compaction phase

4.2. Second experiment setup results

The maximum voltage values read as a result of the 30-second tests performed with the modified proctor mallet on the samples 1-2 and 3 prepared in the second experimental setup are given in Table 5. In addition, the test videos can be watched with the help of the QR code in Figure 8. From the test results, the fact that the piezone is close to the surface on which the force is applied increases the electricity generation potential. It was observed that the diameter of the piezo brass had no effect in terms of electricity generation potential.

The samples were carefully broken to observe the Piezo and connection states in the sample. From the observed results, it was seen that the piezo and its connections were intact (Figure 9).

Table 5. The maximum voltage readings on the samples

Sample No	Maximum Voltage Values (V)
1	0.207
2	0.023
3	0.210

Figure 8. Damaging of series-connected piezo electric sensor after the Marshall compaction phase

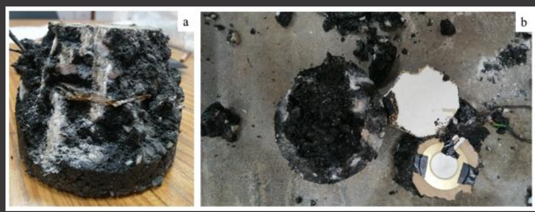

Figure 9. Monitoring the status of the piezo electric sensor and its connections; a) Piezo image embedded in the sample, b) Removing the piezo electric sensor from the sample

5. Conclusions

This study highlights that utilize piezoelectric technology in road energy harvesting is feasible and has a bright future and encourages the autonomy vehicles power demand. The piezoelectric transducers can not only harvest energy from asphalt pavement, but also can be used as smarter sensor to monitor pavement condition under traffic load for the right intervention on right time in the future.

Currently, most of the technologies in the pavement energy harvesting field are in the laboratory and prototype validation phase. However, these technologies will be widely used in the future, especially in urban and metropolitan roads where traffic density is high. The use of the energy obtained from this in signalling lights, led lighted markings, led illuminated road surface markings, led lighting of important traffic safety elements such as bicycle paths, pedestrian crossings, bumps, and night road lighting will also make important contributions to ensuring traffic safety.

As a result of the experimental study, voltage up to 0.210 V was obtained from the asphalt pavements with the impact effect. It is thought that more effective results can be obtained with different types of piezo electrical energy harvesting sensors in future studies. It is thought that especially the flexibility properties of hot bituminous mixtures may be effective in the energy harvesting efficiency to be obtained from this type of piezoelectric sensors.

This type of energy harvesting method would not only be cheap and clean energy resource, but also it will be great contribution for prevention of fossil based environmental degradation.

Declaration of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contribution Statement

All Authors contributed equally at all stages of the study.

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