Kütahya Dumlupınar University
Institute of Graduate Studies

Journal of Scientific
Reports-A
E-ISSN: 2687-6167
Number 51, December 2022

RESEARCH ARTICLE

INVESTIGATION of the ADHESION PROPERTIES and STRENGTH of HOT MIX ASPHALT EXPOSED to SEA WATER

Mehmet SALTAN[1], Öznur KARADAĞ[2,*], Gizem KAÇAROĞLU[3]

[1]Süleyman Demirel University, Engineering Faculty, Department of Civil Engineering, Isparta, mehmetsaltan@sdu.edu.tr
ORCID: 0000-0001-6221-4918
[2*]Süleyman Demirel University, Engineering Faculty, Department of Civil Engineering, Isparta, oznurkaradag92@gmail.com
ORCID: 0000-0003-0755-5626
[3]Süleyman Demirel University, Engineering Faculty, Department of Civil Engineering, Isparta, gizemkacaroglu07@gmail.com
ORCID: 0000-0002-5734-7131

Receive Date:20.06.2022 *Accepted Date: 08.11.2022*

ABSTRACT

The presence of water on pavement causes loss of strength and moisture damage. Therefore, cracks and stripping occur on pavement over time. Pavements in the provinces on the Aegean and Mediterranean coasts are exposed to salty water as a result of overflow of sea due to atmospheric conditions in winter. For example, if wind blows towards the land, water level in sea rises and floods the land. In this study, effects of the Aegean and Mediterranean Sea waters which have different salinity rates on hot mix asphalt were investigated. Both stripping (Nicholson, California and Texas Boiling) and adhesion (Vialit) tests were carried out in order to evaluate the adhesion between aggregates and bitumen in samples which were exposed to Aegean and Mediterranean Sea waters which have different salinity rates. According to the test results, it was observed that the adhesion between aggregates and bitumen decreased with the increase in salinity. The unconditioned indirect tensile strengths of the hot mix asphalt exposed to pure water, Aegean Sea water and Mediterranean Sea water were determined as 798, 730 and 687 kPa respectively, while the conditioned indirect tensile strengths were determined as 725, 478 and 438 kPa. Also, the tensile strength ratios of hot mix asphalt conditioned with pure water, Aegean and Mediterranean Sea water were determined as %91, %68 and %60 respectively. The tensile strength ratios of the samples conditioned with the Aegean Sea and Mediterranean Sea waters have not met the specification limit value. It has been determined that Aegean and Mediterranean Sea waters which have different salinity rates damage to hot mix asphalt. Therefore, it is suggested that, certain features of pavements which built near the seaside should be improved. In literature, effect of solutions formed from the components of sea water on samples prepared in laboratory has been examined, but natural sea water has not been used on samples directly. This circumstance shows the originality of study.

Keywords: *Superpave, Sea water, Hot mix asphalt, Indirect tensile strength, Moisture susceptibility*

1. INTRODUCTION

The presence of water on pavements causes loss of strength and moisture damages. Moisture damage which occurred in asphalt mixtures can be affected by many factors. These are properties of aggregates and bitumen, mixture design and construction (air void ratio, asphalt film thickness, permeability), environmental factors (temperature, life of pavement, freeze-thaw cycles), traffic conditions and the type and properties of materials added to the asphalt mixture [1]. The usage of anti-stripping additives is the most common method which is used to reduce moisture damage of asphalt mixtures. Nano materials (nano ZnO, nano TiO2) were used to increase the resistance to moisture damage of hot mix asphalt (HMA) [2-3]. Also, Surface Free Energy (SFE) method has been used to evaluate the adhesion formed between bituminous binder and aggregates which are coated with polyvinyl chloride in order to reduce moisture sensitivity of asphalt mixtures [4].

While the presence of water on the pavement is a problem on its own, freezing of this water due to atmospheric conditions creates bigger problems. Different anti-icing materials [5] and methods are used to prevent icing on the surface of pavement. The purpose of taking precautions like this is to reduce dangerous driving conditions and to melt the ice formed on the surface of pavement. Salt and calcium-acetate are widely used as de-icer materials. De-icing salts are caused various problems such as environmental pollution, early degradation of asphalt mixture and tire wear. De-icing salts are reduced the freezing temperature of liquids that cause significant hydraulic pressure in asphalt pores. The presence of anti-icing materials on the surface of pavement in the freeze-thaw cycle cause adverse effects on the pavement. It has been stated that in the case of presence of anti-icing chemicals and water flow on the pavement surface, the water flow increases the harmful effects of the chemicals and causes serious stripping during the freeze-thaw cycle [6]. In the winter months, sand-salt mixture is used to prevent freezing which occurs on the pavement. With the melting of the snow or ice, the salt water solution starts to damage to the pavement. Depending on the type and density of the salt, the damage caused by the salt to the pavement varies. For this reason, the effects of salt on the asphalt mixture have been investigated using three tidal waters with different chemical components. Chemical components in tidal waters alone have not caused excessive damage to the pavement. However, a combination and interaction of chemical compounds have had more damage to the pavement [7].

On Egyptian highways, because of the leakage of water between aggregates and bitumen, deteriorations such as stripping and ravelling are observed. Consequently, performance and service life of the pavement are reduced. Asphalt pavements in Egypt are often exposed to sea water and tap water. Therefore, asphalt mixtures prepared in the laboratory have been conditioned with both sea water and tap water, and the strengths and tensile strength ratios (TSR) of the mixtures were examined [8]. Since Bangladesh is a country surrounded by rivers, it may encounter natural disasters such as floods, hurricanes and tides. When these natural disasters occur, the pavement will be exposed mostly to salt water-containing sea waters. It has been known that pavements are affected by sea waters with different salt ratios. For this reason, the effects of salt on bituminous binder and HMA have been examined. It has been seen that, sea water also has indicated an effect exactly like de-icing salts or a sand-salt mixture. The limit value of salt has been determined for HMA samples. As the salt content of bitumen increases, the strength of the mixtures has decreased. For bituminous mixtures, the limit value of salt has been determined as 4%. It has been known that, salts are obtained from sea water or rock beds [9]. In order to increase the performance of asphalt mixtures exposed to sea water, low density polyethylene (LDPE) plastic waste was added in different ratios (1%, 2%, 3%, 4% and 5%) to mixtures. With the use of LDPE in the asphalt mixtures, it is aimed that reducing the waste materials and increasing of the performance of asphalt mixtures. In Marshall Test, it was explained that, even if exposure to sea water, asphalt mixtures containing LDPE improved some properties compared to reference asphalt mixtures [10]. The durability of asphalt mixtures due to tidal floods in the coastal areas are negatively affected. In order to increase the durability and life of asphalt mixtures which are exposed to tidal flood water, crumb rubber has been added to the asphalt mixtures. It has been stated that the skid resistance of asphalt mixtures containing crumb rubber increases [11].

Molten salts that affect the salinity of sea waters are chlorine, sodium, sulphates, magnesium, calcium, potassium bicarbonate and bromine, respectively. These known elements are found in sea waters. Recently, the salinity of sea water is determined with electrical conductivity measurement which is more practical and reliable [12]. Salt (sodium chloride, NACI) was added to the water by weight based on the amount of salt in the Cantabrian Sea (3.5%). Before preparing the asphalt mixtures, the aggregates to be used in the mixture were submerged in salt water. Different test results (Indirect Tensile Strength (ITS), Water Sensitivity (ITSR), Wheel Tracking Test and Cantabro Loss Particle Test) which are occurred on asphalt mixtures show that the properties of the asphalt mixtures adversely affected [13]. In the present study, the properties of asphalt mixtures (ITS, TSR) which were exposed to Aegean and Mediterranean Sea waters which has salinity of 23% and 38% respectively in our country, were investigated. In addition, the adhesion of mixtures (Nicholson and California Stripping, Vialit and Texas Boiling tests) conditioned with sea water which has different salinity ratios between aggregates and bitumen was evaluated.

2. MATERIALS and METHODS

2.1. Materials

2.1.1. Aggregates

The limestone aggregates were used in current study. Specific bulk gravity (TS EN 1097-6), water absorption, Los Angeles (ASTM C 131-03) and micro-deval abrasion tests (TS EN 1097-1) were performed on limestone aggregates. Test results of these tests can be seen in Table 1.

Table 1. Physical characteristics of aggregates.

Properties	Coarse aggregates	Fine aggregates	Filler
Specific gravity (g/cm^3)	2.701	2.606	2.501
Los Angeles wear loss (%)	18.48	-	-
Micro-Deval wear loss (%)	9.95	-	-

2.1.2. Bitumen

Bitumen which was used in current study has 50/70 penetration grade. Results of conventional tests which were applied on the bitumen are given in Table 2.

JSR A
Journal of Scientific Reports

Table 2. Characteristics of bitumen.

Test	50/70 Bitumen	Standard
Penetration (25˚C)	54	TS EN 1426
Softening point	49.8	TS EN 1427
Ductility (5cm/min)	>100	TS EN 13589
Specific gravity (g/cm^3)	1.021	TS EN 15326+A1

2.1.3. Aegean sea and mediterranean sea waters

Sea water may overflow to land due to atmospheric conditions (wind, rain, storm, tide, etc.) in the winter. This situation is also experienced in our provinces close to the Aegean Sea and Mediterranean Sea (Figure 1). In this study, the effects of sea waters with different salinity ratios on HMA was studied. In our country, salinity ratios of these sea waters are known as 23‰ and 38‰, respectively. Samples which prepared in the laboratory were exposed to Aegean Sea and Mediterranean Sea waters.

Figure 1. Flooding of sea water in İzmir and Antalya provinces.

2.2. Methods

2.2.1. Adhesion and stripping tests

The presence of water in the HMA causes a decrease in the adhesion between aggregates and bitumen. Over time, cracks and stripping occur in HMA. In this study, the effects of the Aegean Sea and Mediterranean Sea waters which have different salinity ratios on stripping behaviours and adhesion between aggregates and bitumen were investigated with the Nicholson and California Stripping, Vialit and Texas Boiling tests.

Stripping tests are implemented to determine the resistance of pavements to negative effects of water and traffic. According to this, Nicholson and California stripping tests was performed using both pure water and Aegean Sea and Mediterranean Sea waters.

Vialit is known as a test that performed to determination of the level of decreases in the adhesion between aggregates and bitumen with the effect of water. So, this method was also used to investigation of the effects of sea waters on adhesion properties of pavements in current study. In addition to Vialit, Texas Boiling test was also conducted to examine the effects of boiling action of water on the adhesion between aggregates and bitumen. 250 gr aggregate samples are prepared with the fractions of 8/11.2 mm. Loose asphalt mixture is obtained by adding bitumen up to 3% the weight of the prepared aggregate sample. Loose asphalt mixture which has temperature of 85-100 ℃ is added to 500 ml of boiling distilled water and it is allowed to boil for 10 minutes. After the test period is completed, the aggregates are placed on towel paper. Then, aggregates which covered with bitumen are determined observationally.

2.2.2. Superpave volumetric mix design

Superpave is a performance–based method which was developed for determining the properties of asphalt binders and aggregates, designing asphalt mixes and analysing pavement performance. This method includes tests which are taken into account the specifications of aggregate and asphalt binders to design the hot mix asphalt and analyse performance of HMA. It is commonly used for obtaining a well-performing mix. To obtain a well-performing mixture, in terms of Superpave process, selection of materials and volumetric proportioning of them are important. The four steps which are taken into consideration in testing and analysis process for Superpave method are;

- selection of materials (aggregate, binder, modifiers),
- selection of a design aggregate structure,
- selection of a design asphalt binder content,
- evaluation of moisture susceptibility of the design mixture.

The temperature values and traffic volume of region where the asphalt pavement will be constructed are also important in this method. To properly consider mix design, design ESALs of 20-years are always used. Voids in mineral aggregate (WMA) which is affected by both the aggregate gradation and the properties of aggregates, voids filled with asphalt (VFA) limit values and 4% air void are taken into consideration on calculation the optimum bitumen content (FHWA, 2000; FHWA, 2001).

2.2.3. Indirect tensile strength

The adhesion which is formed between aggregates and asphalt binder is known as a property that affects pavement performance. The presence of moisture between asphalt binder and aggregates causes loss of bonding and stripping. Therefore, Superpave volumetric mix design determines whether the mixture which is consisted of asphalt binder and aggregates is sensitive to moisture. Indirect tensile strength (ITS) test is used in determination of the moisture susceptibility of the unconditioned and conditioned mixtures in accordance with AASHTO T-283 standard. The mixtures which were prepared by considering optimum bitumen content are compacted with Superpave gyratory compactor.

The ITS values of cylindrical samples are determined with the Eq. 1 given below. Afterwards, for all samples, unconditioned (ITSdry), conditioned (ITSwet) values are saved and the Eq. 2 is used for the calculation of TSR values. The minimum limit for the TSR value is 80%. It means that mixtures with a value of less than 80% will exhibit a stripping problem after construction (FHWA, 2000).

JSR A
Journal of Scientific Reports

Karadağ, et all., Journal of Scientific Reports-A, Number 51, 283-296 December 2022.

$$S_t = \frac{2P}{\pi t D} \quad (1)$$

Where St, tensile strength; P maximum load; t, sample thickness and D, sample diameter.

$$\text{TSR} = \frac{ITS_{wet}}{ITS_{dry}} \quad (2)$$

Where TSR, tensile strength ratio; ITSwet, average tensile strength of conditioned specimen; ITSdry, average tensile strength of unconditioned specimen.

3. RESULTS

3.1. Results of Adhesion and Stripping Tests

The Nicholson stripping test, the percentage of aggregates remaining without stripping in the samples exposed to pure water, Aegean and Mediterranean Sea waters was determined as 81, 78 and 3, respectively. In addition, the California stripping test the percentage of aggregates remaining without stripping in the samples exposed to pure water, Aegean and Mediterranean Sea waters was determined as 94, 92 and 86, respectively (Figure 2).

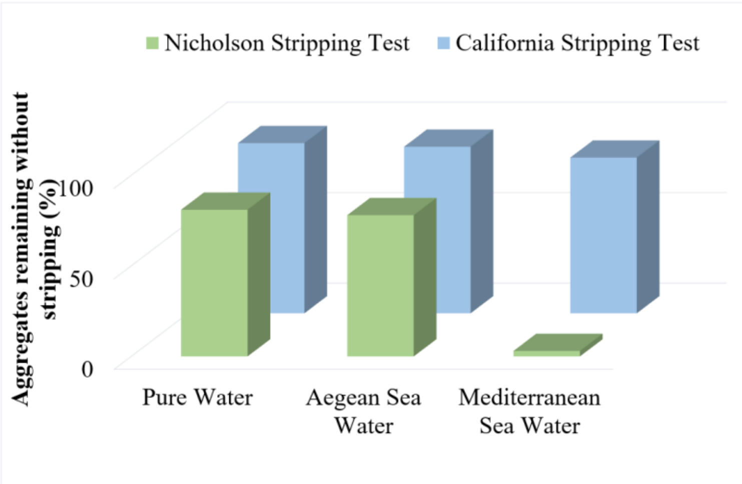

Figure 2. Results of Nicholson and California stripping tests.

In the Nicholson test, it was observed that almost all of aggregates exposed to Mediterranean Sea water were stripped (Figure 3). It can be seen that, number of aggregates remaining without stripping have not met the specification limit value of 60%. Mediterranean Sea water which has high salinity rate has reduced the adhesion between aggregates and bitumen. Measures against stripping (such as anti-stripping additives) should be taken in HMA which exposed to Mediterranean Sea water.

JSR A
Journal of Scientific Reports

Karadağ, et all., Journal of Scientific Reports-A, Number 51, 283-296 December 2022.

Figure 3. Nicholson samples which conditioned with Mediterranean Sea.

As for the California stripping test, the percentage of aggregates remaining without stripping meets the specification limit value of 60%. Since Mediterranean Sea water has a higher salinity than Aegean Sea water, it has been observed that more aggregates were stripped. According to the obtained results, the salinity of sea water affects the adhesion between aggregates and bitumen. This result can be supported with a similar study which stated that waters with high acidity such as sea water negatively affect the adhesion between aggregates and bitumen because accelerate oxidation of asphalt [16]. Sea water affects the adhesion between aggregates and bitumen by facilitating the molecular migrations of bitumen components and weakening the agglomeration of asphaltene [17]. Thus, HMA which exposed to sea water must be resistant to stripping.

When the graph which is given in Figure 4 was examined, while the number of aggregates falling from the sample exposed to pure water was 3%, the number of aggregates falling from the samples exposed to Aegean and Mediterranean Sea waters which has different salinity ratios was determined as 4% and 6%, respectively. According to the obtained results, the adhesion between aggregates and bitumen was affected negatively in samples exposed to Aegean Sea and Mediterranean Sea waters which has different salinity ratios.

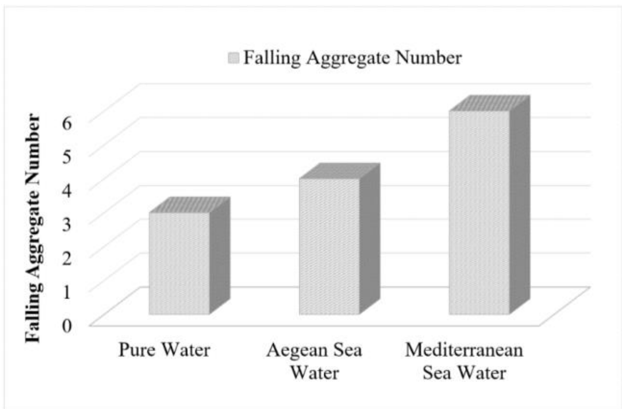

Figure 4. Vialit test results.

JSR A
Journal of Scientific Reports

In the Texas Boiling test, the number of aggregates covered with bitumen was 31% when conditioned with pure water, while the number of aggregates covered with bitumen was determined as 21% and 17%, respectively, when conditioned with Aegean and Mediterranean Sea waters (Figure 5). When the graph which is given in Figure 5 was examined, it was observed that sea waters which have different salinity ratios affect the adhesion between aggregates and bitumen. Since Mediterranean Sea water is saltier, the number of aggregates which covered with bitumen is the least. It has been observed that the adhesion between aggregates and bitumen decreases with increasing of salinity ratio in water. In addition, it can be seen that the results of the adhesion and stripping tests which performed in this study are consistent.

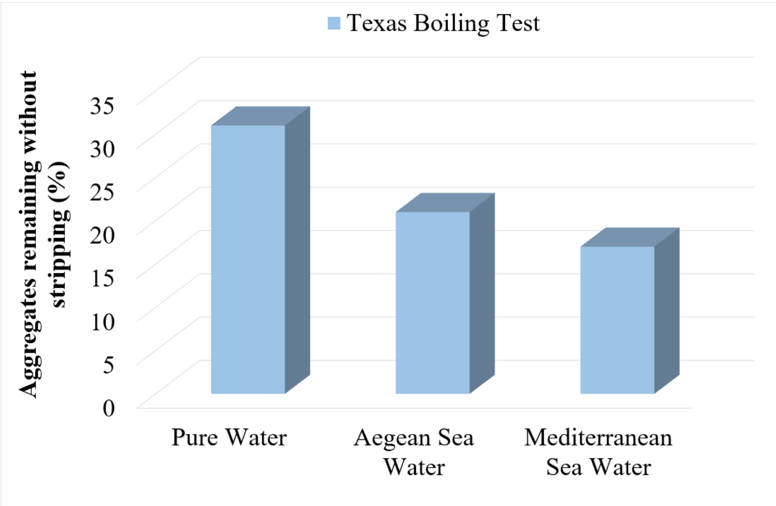

Figure 5. Texas boiling test results.

3.2. Optimum Bitumen Content

In order to determine the optimum bitumen content, mixtures were prepared by using bitumen at the rates of 4.5%, 5%, 5.5%, 6% and the compaction of them was provided with gyratory compactor. Initially, the bitumen content which corresponds to 4% air void was determined from the air void graph. Then, it was checked whether the determined bitumen content has provided the requirements of VMA and VFA. After these steps, the optimum content of bitumen for reference bitumen was determined as 5.20%. Obtained results are given in Figure 6.

JSR A
Journal of Scientific Reports

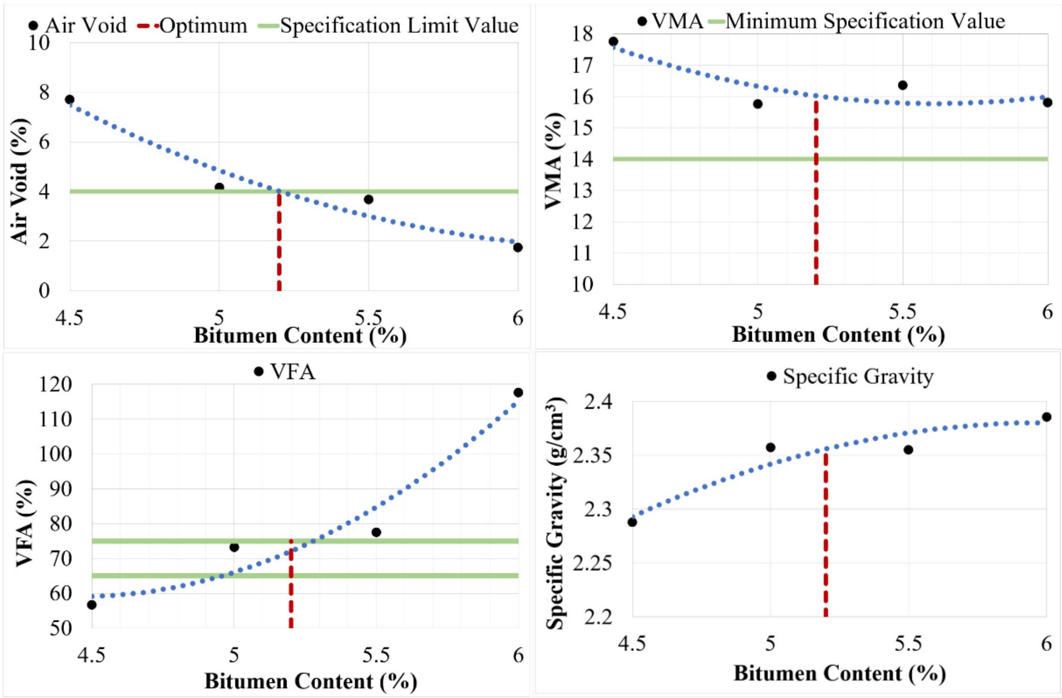

Figure 6. Graphs of reference bitumen.

3.3. Evaluation of Moisture Susceptibility

So as to evaluate the moisture susceptibility, ITS test was performed on the mixtures which were prepared by using determined optimum bitumen content. Unconditioned and conditioned ITS and TSR values were found for samples tested with Aegean Sea, Mediterranean Sea waters and pure water. The unconditioned indirect tensile strengths of the hot mix asphalt exposed to pure water, Aegean Sea water and Mediterranean Sea water were determined as 798, 730 and 687 kPa respectively, while the conditioned indirect tensile strengths were determined as 725, 478 and 438 kPa. Also, the tensile strength ratios of hot mix asphalt conditioned with pure water, Aegean and Mediterranean Sea water were determined as %91, %68 and %60 respectively (Figure 7-8).

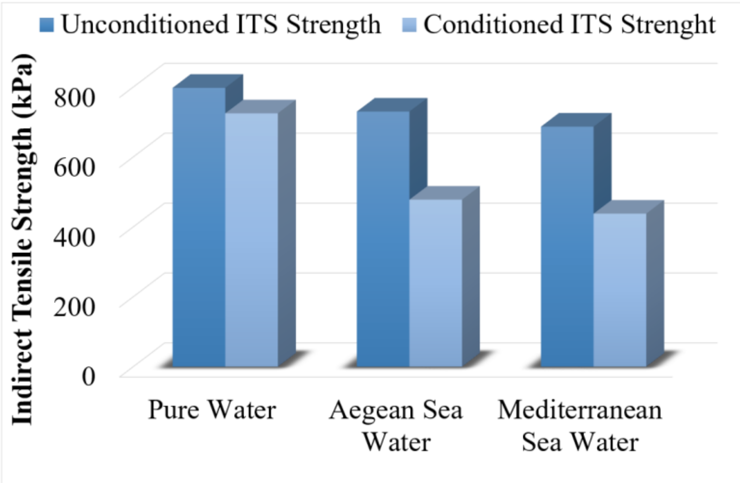

Figure 7. ITS results of samples.

When the graph given in Figure 7 is examined, it can be seen that the samples conditioned with pure water provides better strength than the samples which conditioned with Aegean Sea and Mediterranean Sea waters. In addition, the strength of the samples conditioned with Mediterranean Sea water which is saltier than Aegean Sea water is less. The salinity of sea water also affects the strength of the samples which were prepared by the Superpave method. This result can be supported with a similar study which stated that concrete samples exposed to the magnesium sulphate and sea water for certain periods decrease their strength [18]. In the light of the obtained results, it is observed that sea water reduces the stripping resistance and unconditioned and conditioned tensile strengths of HMA.

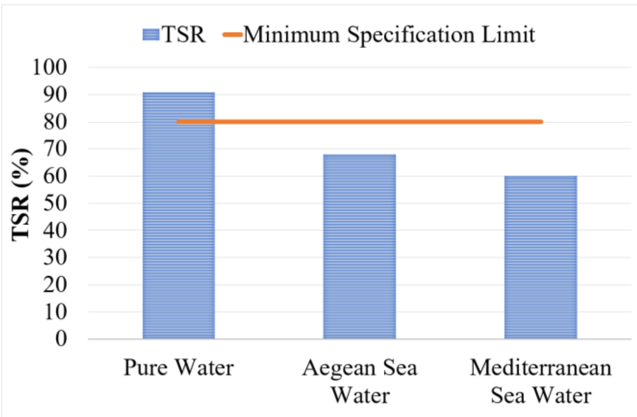

Figure 8. TSR results of samples.

When Figure 8 was examined, it can be seen that the TSR values of the samples conditioned with the Aegean Sea and Mediterranean Sea waters have not met the specification limit value. Samples conditioned with sea waters increased moisture susceptibility compared to samples conditioned with pure water. The ITS values and moisture susceptibility of the samples conditioned with sea waters which have different salinity rates have decreased and increased, respectively. According to the obtained results, it can be said that sea water affects negatively the properties of HMA. Therefore, necessary measures should be taken to increase the stripping resistance and strength of the pavement that will be exposed to sea water.

In this study, it was exhibited that the stripping resistance, unconditioned and conditioned ITS values of HMA which conditioned with sea waters which have different salinity ratios have decreased. Also, according to tensile strength values, moisture susceptibility of samples exposed to sea waters have increased (Table 3).

Table 3. The results of hot mix asphalt exposed to sea water.

RESULTS OF HOT MIX ASPHALT EXPOSED TO SEA WATER							
Water Types	**Adhesion and Stripping Tests**				**Indirect Tensile Strength (ITS) Tests**		
	Nicholson Stripping	**California Stripping**	**Texas Boiling**	**Vialit Test**	**Unconditioned ITS (kPa)**	**Conditioned ITS (kPa)**	**TSR (%)**
	Aggregates remaining without stripping (%)			Falling aggregates number (%)			
Pure Water	81	94	32	3	798	725	91
Aegean Sea Water	78	92	21	4	730	478	68
Mediterranean Sea Water	3	86	17	6	687	438	60

4. CONCLUSION

The presence of water on the pavement decreases the adhesion between aggregates and bitumen, and correspondingly, cracks and stripping occur over time. Sea waters can overflow to land due to atmospheric conditions such as rain, wind, storm and tide etc. However, no study has been conducted on how the pavement is affected in the presence of sea water on it in our country. In this study, certain properties of HMA were investigated using natural Aegean Sea and Mediterranean Sea waters. The obtained results are as follows:

• Stripping tests were carried out to examine how the Aegean Sea and Mediterranean Sea waters with different salinity ratios affect the adhesion between aggregates and bitumen. The Nicholson stripping test, the percentage of aggregates remaining without stripping in the samples exposed to pure water,

Aegean and Mediterranean Sea waters was determined as 81, 78 and 3, respectively. It was observed that, aggregates exposed to Mediterranean Sea water which is saltier than Aegean Sea water were stripped approximately 100% in the Nicholson stripping test. In the California stripping test, it has seen that the percentage of aggregates remaining without stripping in the samples exposed to pure water, Aegean and Mediterranean Sea waters was determined as 94, 92 and 86, respectively. According to the obtained results, it can be said that, sea water has reduced adhesion between aggregates and bitumen.
• In the Vialit test, while the number of aggregates falling from the sample exposed to pure water was 3%, the number of aggregates falling from the samples exposed to Aegean and Mediterranean Sea waters which has different salinity ratios was determined as 4% and 6%, respectively. According to the obtained results, the adhesion between aggregates and bitumen was affected negatively in samples exposed to Aegean Sea and Mediterranean Sea water which has different salinity ratios. In the Texas Boiling test, it was observed that sea waters which have different salinity ratios affect the adhesion between aggregates and bitumen. Since Mediterranean Sea water is saltier, the number of aggregates which covered with bitumen is the least.

• The unconditioned indirect tensile strengths of the hot mix asphalt exposed to pure water, Aegean Sea water and Mediterranean Sea water were determined as 798, 730 and 687 kPa respectively, while the conditioned indirect tensile strengths were determined as 725, 478 and 438 kPa. According to the obtained results, samples conditioned with Mediterranean Sea water have put up less strength than samples conditioned with Aegean Sea water. The reason for this is that, the salinity of Mediterranean Sea water is higher than that of Aegean Sea water.

• The tensile strength ratios of hot mix asphalt conditioned with pure water, Aegean and Mediterranean Sea water were determined as %91, %68 and %60 respectively. The TSR values of the samples conditioned with the Aegean Sea and Mediterranean Sea waters have not met the specification limit value. Samples conditioned with sea waters increased moisture susceptibility compared to samples conditioned with pure water.

ACKNOWLEDGEMENT

This research received no financial supports from any funding agency in public, commercial or non-profit sectors.

REFERENCES

[1] Amini, B., Tehrani, S.S., (2014), Simultaneous effects of salted water and water flow on asphalt concrete pavement deterioratiob under freeze-thaw cycles, International Journal of Pavement Engineering, 15(5), 383-391.

[2] Azarhoosh, A., Moghaddas Nejad, F., Khodaii, A., (2018), Evaluation of the effect of nano-TiO_2 on the adhesion between aggregate and asphalt binder in hot mix asphalt, European Journal of Environmental and Civil Engineering, 22(8), 946-961.

[3] Behiry, A. E. A. E. M., (2013), Laboratory evaluation of resistance to moisture damage in asphalt mixtures, Ain Shams Engineering Journal, 4(3), 351-363.

[4] Can, M., Etemoğlu, A. B., Avcı, A., (2002), Atıf analizi: Deniz suyundan tatlı su eldesinin teknik ve ekonomik analizi [Citation analysis: Technical and economical analysis of desalination processes], Uludağ Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, 7(1), 147-160.

[5] Hamedi, G. H., (2018), Effects of polymeric coating the aggregate surface on reducing moisture sensitivity of asphalt mixtures, International Journal of Civil Engineering, 16(9), 1097-1107.

[6] Hamedi, G. H., Nejad, F. M., Oveisi, K., (2016), Estimating the moisture damage of asphalt mixture modified with nano zinc oxide, Materials and Structures, 49(4), 1165-1174.

[7] Kakisina, E. M., Makmur, A., Salim, F. D., (2019), Influence of LDPE plastic waste on asphalt mixture soaked in sea water, IOP Conference Series: Earth and Environmental Science, 19-20, Johor, Malaysia.

[8] Li, F. and Wang, Z., (2012), Experiment on road performance of asphalt mixture with automatic long-term snowmelt agent, Journal of Highway and Transportation Research and Development (English Edition), 6(4), 11-17.

[9] Özen, H., (2011), Rutting evaluation of hydrated lime and SBS modified asphalt mixtures for laboratory and field compacted samples, Construction and Building Materials, 25(2), 756-765.

[10] Setiadji, B. H., Utomo, S., (2017), Effect of chemical compounds in tidal water on asphalt pavement mixture, International Journal of Pavement Research and Technology, 10(2), 122-130.

[11] Martina, N., Hasan, M. F. R., Setiawan, Y., Yanuarini, E., (2021), Analysis of the use of rubber waste to improve the performance of the asphalt concrete mixture against tidal floods, In IOP Conference Series: Earth and Environmental Science, 739 (1), 012005.

[12] Shahin, M., Khokon, Z. H., Sobhan, M. A., Ahmed, T. U., (2015), Salt tolerance limit of bituminous pavement, International Journal of Civil Engineering, 2(4), 1-7.

[13] Juli-Gandara, L., Vega-Zamanillo, A., Calzada-Perez, M. A., (2019), Sodium chloride effect in the mechanical properties of the bituminous mixtures, Cold Regions Science and Technology, 164, 102776.

[14] United States Department of Transportation Federal Highway Administration, (2000), Superpave Fundamentals Reference Manual, Washington, DC, USA.

[15] United States Department of Transportation Federal Highway Administration, (2001), Superpave Mixture Design Guide, Washington, DC, USA.

[16] Sugiyanto, G., Widarini, W., Indriyati, E. W., (2022), The effect of sea water immersion on buton asphalt (as-buton) mixture, Jurnal Teknologi, 84(1), 29-39.

[17] Long, Z., Tang, X., Ding, Y., Miljkovic, M., Khanal, A., Ma, W., You, L., Xu, F., (2022), Influence of sea salt on the interfacial adhesion of bitumen-aggregate systems by molecular dynamics simulation, Construction and Building Materials, 336, 124471.

[18] Kuyumcu, H. M., (2006), In concrete resist effects of sea water and with sulphate water, Master's thesis, Sakarya University.