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EFFECT OF CHEMICAL ADDITIVES ON THE PERFORMANCE OF ASPHALT PAVEMENT EXPOSED TO WASTEWATER

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Abstract

It is known that water is the first enemy of asphalt pavement, and its danger increases when the water is a product of sewage because it contains organic materials and acids. The most common technique to mitigate moisture damage is using additives or modifiers with the asphalt binder. This research aims to study the effect of wastewater on the mechanical properties of HMA containing chemical additives. Three different chemical additives were used. The chemical additives were Addicrete PVS, Adibond 65, and Silica Gel that were added with different percentages 5, 10, 15, and 20 % by the weight of optimum asphalt content (OAC) in addition to the original mix. Asphalt 60/70 was mixed with several concentrations of each additive by using a high shear mixer at a temperature of 130 ^{0}C and a speed of 4000 rpm for 30 minutes. All asphalt mixtures were submerged in wastewater for 3, 7, and 15 days. Marshall and Indirect tensile strength tests were performed on these exposed mixtures. despite the wastewater decreased the mechanical properties of all mixtures, the additives decrease that effect with pronounced values. The results showed that the best content for adding these additives to the mixture was 10% for using Addicrete PVS and Silica gel while it was 5% for using Adibond 65. The best additive was Addicrete PVS with 10% content as it gives the highest value of Marshall stability, Marshall stiffness, Marshall quotient, and indirect tensile strength.

Keywords: Addicrete PVS, Adibond 65, Silica gel, and hot mix asphalt

1. Introduction

Moisture is one of the foremost sources of deterioration in flexible pavements. Moisture damage described as the degradation of the mechanical properties of specimens brought on by using moisture [1]. Bhasin et al. mentioned that most of the early checks for quantifying moisture damage focused on evaluating mechanical residences earlier than and after a conditioning process [2]. Putman and Amirkhanian compared the performance of Stone Matrix Asphalt (SMA) mixtures containing waste tire and carpet fibers with mixes made with commonly used cellulose and polyester fibers. The results revealed that the tire, carpet, and polyester fibers significantly improved the toughness of the mixtures, but no significant difference in permanent deformation or moisture susceptibility was found [3]. Ghada S. Moussa et al studied the impact of using high-density polyethylene [HDPE]on the moisture susceptibility of asphalt mixtures. The results were concluded that implementing HDPE as a binder-additive improved the binder-aggregates bonding and consequently higher moisture resistance was gained [4]. Moghadas Nejad et al. concluded that the adhesion between the binder and aggregates in a modified mixture with HDPE was increased despite the sample exposed to moisture [5]. M. Rasel et al. investigated the effect of adding PVC (2.5% to 20 % by weight of bitumen) at optimum bitumen content on the performance of bitumen grade 80/100. The results indicated that using PVC modified the bitumen properties consequently obtained a high strength mixes [6]. Prasad. B et al. assessed the performance of modified bitumen with plastic waste. The plastic waste was once introduced (1% - 9%) via the weight of the recycled bitumen. The outcomes confirmed that adding plastic waste improved the binding property, stability, density, and resistance to water [7]. Rahman, Md et al. employed two sorts of polymer the PVC and waste polyethylene to improve the performance of the asphalt mixture. The results concluded that adding waste polyethylene modifier up to 10% and waste PVC modifier up to 7.5% can be used for flexible pavement construction in a warmer region due to the high values of stability, stiffness, and voids characteristics [8]. Goh, S.W. et al. concluded that using Nano clay and carbon microfiber enhanced the mixture's performance against moisture damage [9]. The stress of vehicle wheels alongside the presence of water on the avenue surface motive the stripping of the asphalt mixture. Stripping occurs when the bond between the asphalt and the mixture is damaged via water. The water may additionally be dispatched on or in the aggregate due to the fact of incomplete drying or it can also come from some different supply after construction [10]. Attaelmanan concluded that the durability of asphalts is mostly influenced by their chemical composition [11]. Mahabir Panda et al. used reclaimed low-density polyethylene (LDPE) from carrying bags of goods for enhancing mixture performance against fatigue life, resilient modulus, resistance to moisture susceptibility as well as Marshall characteristics [12]. Hugo et al. pronounced three test methods to study the properties of bitumen-rubber binders and asphalt. The sliding plate rheometer tests for bitumen-rubber binder while tensile strain measurement and freeze-thaw test for bitumen-rubber asphalt [13]. The research gap is Limited research studies have been investigated on the effect of wastewater on the performance of hot mix asphalt.

The research objective is to study the effect of using different types of chemical additives such as Addicrete PVS, Adibond 65, and Silica gel on the reduction of the effect of wastewater.

The Research Methodology: To achieve the objectives of this research work, the following work tasks which are outlined in were conducted:

- Review the benefits of the different additives on pavement performance.
- Select the mixed materials and the types of additives to be used in this study.
- A conventional control mix designed using Marshall method was used with different types and amounts of each additive to find out the

optimum percent of each modifier.

- The influence of the modified binder on the HMA properties was studied through laboratory testing.
- To study the effect of wastewater on the performance of asphalt mixtures modified with different additives the samples were submerged on wastewater for 3,7and 15 days and Marshall properties and indirect tensile strength was calculated in both dry and submerging conditions.

2. Materials

2.1. Aggregate

The crushed limestone was used as a coarse aggregate, siliceous sand as a fine aggregate, and limestone dust as mineral filler. The aggregate gradation was selected according to one of the commonly used gradations of the Egyptian code 2008 (Dense gradation 4C). The gradation of the combined aggregate along with the specification limit is presented in Figure1. The nominal maximum aggregate size was 19.5 mm. The physical properties of the aggregate used in the study were presented in Table 1.

Table 1. Physical Properties of Aggregates

Test	Results				Standard Test Method
	S1	S2	Sand	Mineral Filler	
Bulk Specific Gravity	2.619	2.628	2.630	-	ASTM C127 [14] ASTM C128 [15] ASTM D854 [16]
SSD Specific Gravity	2.668	2.701	2.730	-	
Apparent Specific Gravity	2.728	2.756	2.781	2.632	
Water Absorption (%)	1.95	1.4	2.940	-	
Los Angeles	29.2		-	-	ASTM C131 [17]

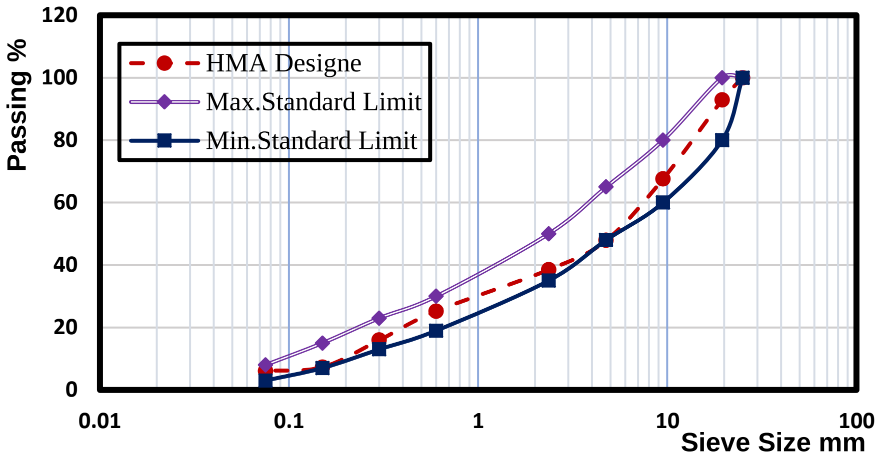

Fig.1. Mixture Aggregate Gradation

2.2. Asphalt cement

The asphalt cement used was AC 60/70. This asphalt material supplied by Suez Oil Processing Company is the usual asphalt grade used for asphalt pavement construction in Egypt. The physical properties of asphalt cement used are shown in Table 2.

Table 2. Physical properties of bituminous materials

Test	Standard	AC 60/70
Penetration (0.1mm, 25◦C, 5 sec.)	ASTM D5	66
Softening Point (ring and ball), °C	ASTM D36	52
Flashpoint (°C)	ASTM D92	250
Specific gravity at 25 ºC	ASTM-D70	1.02
Penetration index (PI)		0.438

2.3. Additives

Three types of chemical additives were used in this work were Addicrete PVS, Adibond 65, Silica gel. These materials have wide use in the field of concrete, as:

- Addicrete PVS is used to produce concrete with high final and early resistance.
- Adibond 65 is a superplasticizer matter used to increase the bond between the mix component.
- Silica gel is a material that absorbs moisture.

In this research, we study the validity of using these materials as modifiers used in the field of asphalt pavement by studying the effect of these materials on the performance of asphalt mixtures. The properties of the additives were shown in Table 3 and Table 4. The contents of additives in asphalt mixtures were 5%, 10%, 15%, and 20% by the weight of optimum asphalt content (OAC). The additives were mixed with an asphalt binder via a wet mixing process using a high shear mixer at a temperature of 130^{0}C and a speed of 4000 rpm for 30 minutes.

Table 3. The properties of Addicrete PVS [18].

Property	Addicrete PVS	Adibond 65
Density at (kg/L)	1.21± 0.01 at 29^{o}c	1.01 at 27^{o}c
Type	Superplasticizer	Emulsion (Latex Betadine Styrene)
Solubility in water	Soluble	Soluble
Physical State	Brown liquid	clear white liquid
PH	-	10.5
The ratio of Solid Material	-	44.55

Table 4. The properties of Silica Gel [19].

Molar weight at 25 ^{o}c	60.08g/ mole
Chemical formula	SiO2
Solubility in water	Insoluble
Physical state	Transparent beads

2.4. Wastewater

The wastewater used in this research is sewer water taken from the collection station of Assuit University. Table 5 presents the concentration of the sample component with mg for the liter of wastewater sample.

Table 5. Analysis of wastewater sample

Test	Measurement Result
Ammonia mg/l	0.1
Nitrates mg/l	-
PH	7.92
Temperature ^{o}c	20
Dissolved Oxygen mg/l	4
COD mg/l	5
BOD mg/l	-
Sulfate mg/l	20
Manganese mg/l	-

3. Experimental Work

The coarse aggregate, fine aggregate, mineral filler, and asphalt cement were used to prepare the Marshall test specimens with 65 mm height and 101.6 mm diameter. The graduate was chosen for the tested asphalt concrete mixes as shown in Fig.1. According to the design of the mixture, the optimum asphalt content was 4.8 % by weight. After Preparing the specimen it submerged into the wastewater for a different day as 3,7 and 15 days.

3.1. Marshall test

Additives were added separately with different concentrations to asphalt cement and 39 Marshall specimens were prepared. After mixing hot aggregate with asphalt cement with chemical modifiers, samples were compacted using a Marshall hammer with 75 blows /side to represent heavy traffic volume. Marshall test was conducted on both control and chemicals modifier mixes to evaluate their performance. Mixing and compaction temperatures for base asphalt binder were estimated using rotational viscosity at 135^{o}C and 165^{o}C. The ranges of mixing and compaction temperatures for binder were (154.1-158.16) ^{o}C and (141.83-147.95) ^{o}C, respectively.

3.2. Indirect tensile test

The mold of the indirect tensile test was the same as Marshall mold, also 39 specimens were tested. The indirect tensile strength and failure strain were evaluated for both control and chemical modifiers mixtures. The samples were tested in a dry state at a temperature of 25^{o}C with a loading rate of 50.8 mm/minute until the occurrence of the collapse with recording the failure load according to ASTM D6931 - 17 [20].

4. Test Results

4.1. Marshall test results

4.1.1. Effect of type of additive on Marshall stability

Figures (2,3 and 4) show the test results of Marshall stability of Addicrete PVS, Adibond 65, and Silica Gel respectively at different contents versus submerging time. The value of stability is decreased as the time of submerging increased for all tested molds as shown in the figures. This result may be because of wastewater which caused erosion of the sample due to breaking the bond between mixed components. It is found that the value of Marshall stability is approximately the same as dried original compared to the sample modified with 10% content of Addicrete PVS, 5% of Adibond 65, and 10% of Silica Gel after 15 days of submerging. These results may come up because using the different additives increased the stiffness of the mix to resist the erosion thus the mix was able to resist the external loads.

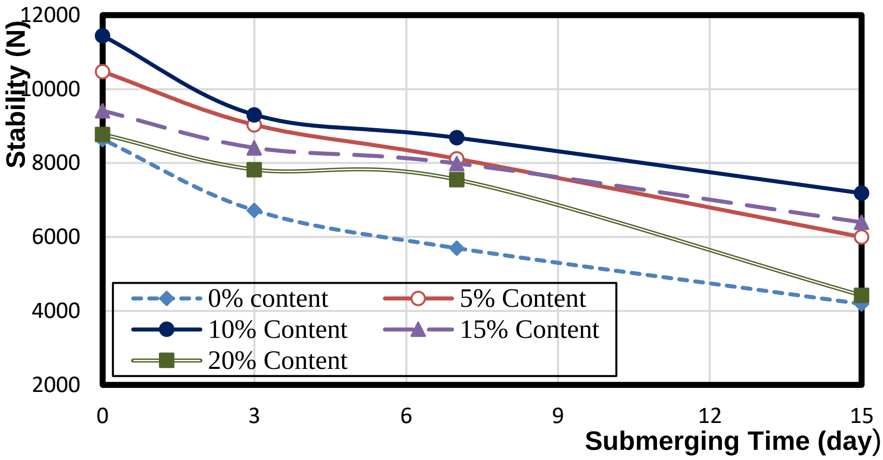

Fig.2. Effect of submerging time on Marshall stability for Addicrete PVS

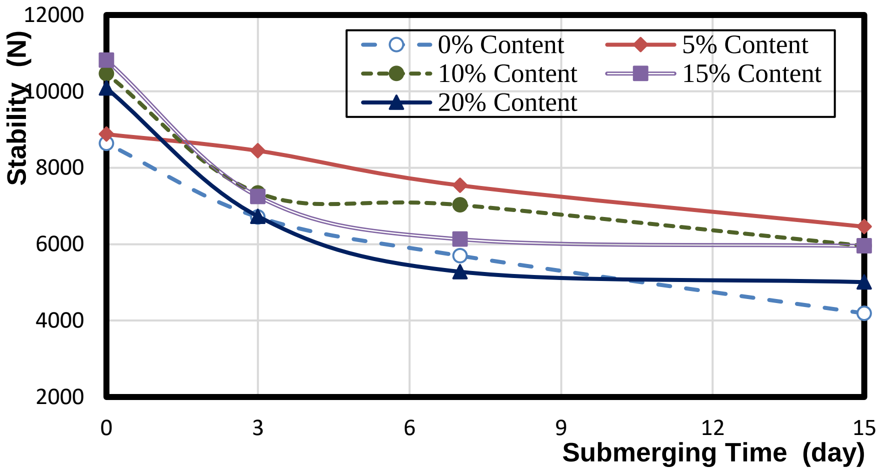

Fig.3. Effect of submerging time on Marshall stability for Adibond 65

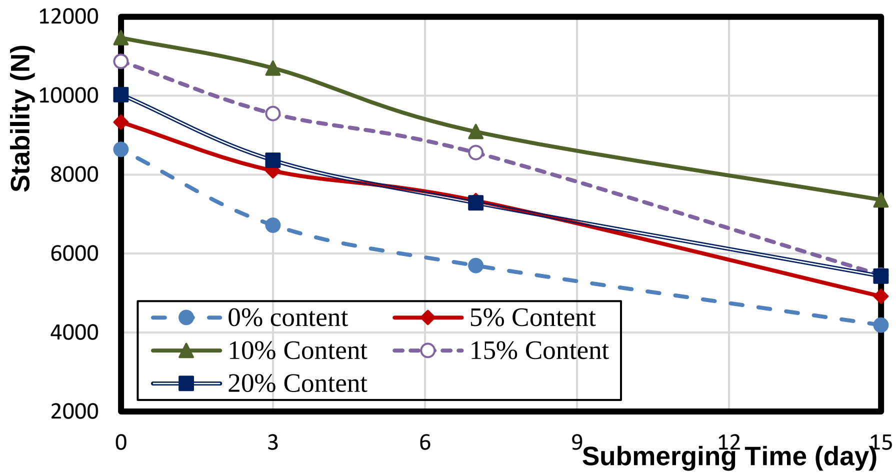

Fig.4. Effect of submerging time on Marshall stability for Silica Gel at different contents.

4.1.2. Effect of type of additive on Marshall flow

The relation between Marshall flow for modified mixtures with Addicrete PVS, Adibond 65, and Silica Gel at different contents and submerging time were shown in Figures (5, 6, and 7) respectively. The value of flow is increased as the time of submerging increased for all tested molds as shown in the figures. The value of Marshall flow for modified mixtures was higher than the control mixture because adding different additives increase the value of Marshall stability. Also, the control mixtures had the lowest value of flow for all tested molds due to their low stability value as shown in the figures above.

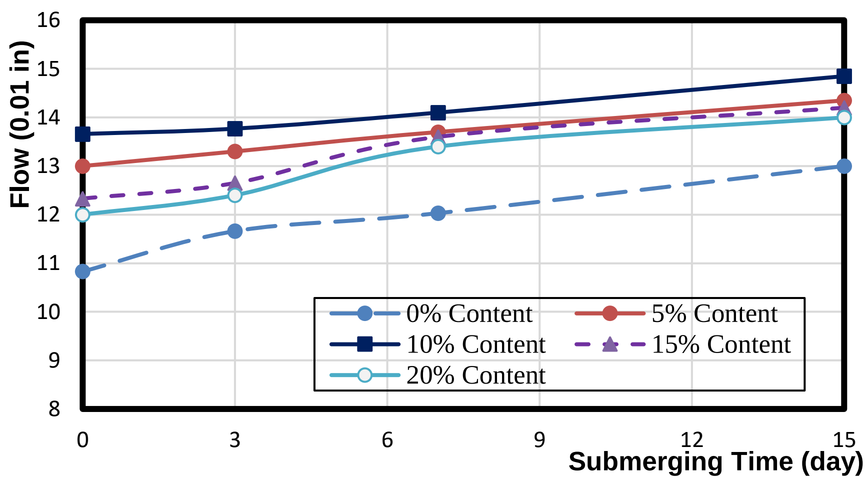

Fig.5. Effect of submerging time on flow for Addicrete PVS

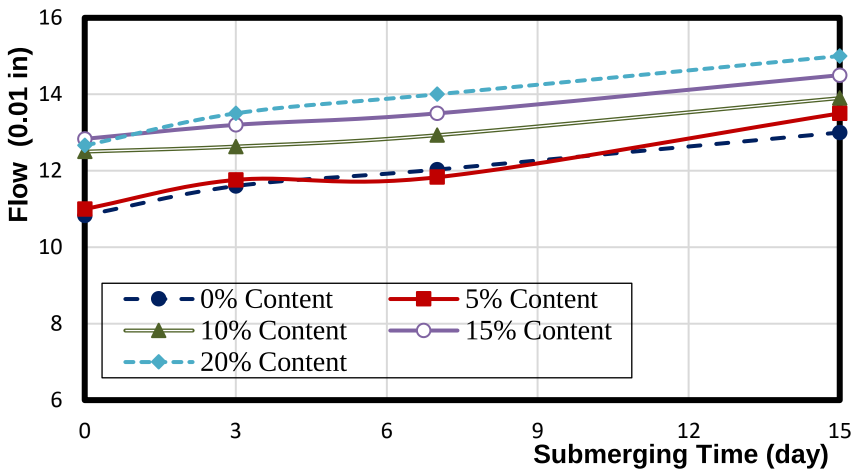

Fig.6. Effect of submerging time on flow for Adibond 65.

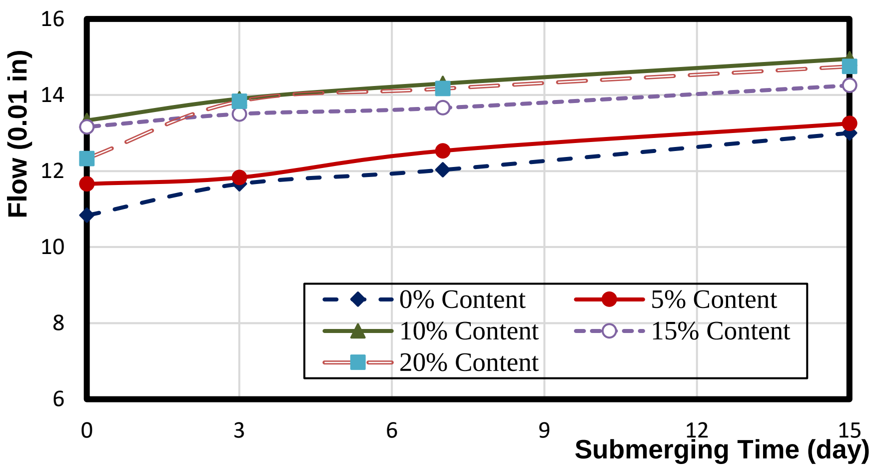

Fig.7. Effect of submerging time on flow for Silica Gel.

4.1.3. Effect of type of additive on bulk density

Figures (8, 9, and 10) show the test results of bulk density for Addicrete PVS, Adibond 64, and Silica Gel respectively at different contents versus submerging time. The value of bulk density is increased as the time of submerging increased for all tested molds as shown in the figures. It reveals that the control mixtures had the highest value of bulk density than mixtures modified with Addicrete PVS and Silica Gel. This result may come up because the wastewater filled almost the voids between the mixture component which increased the weight of the sample consequently increased the density. Using Addicrete PVS and Adibond 65 decreased the value of bulk density than the control mix. These results may be due to using the additives prevented some of the water to permeate through the voids between the mixture component thus the weight of the sample was less than the unmodified sample. While modified mixtures with Silica Gel at 10% content had the highest bulk density in comparison to the original one as shown in Figure 10.

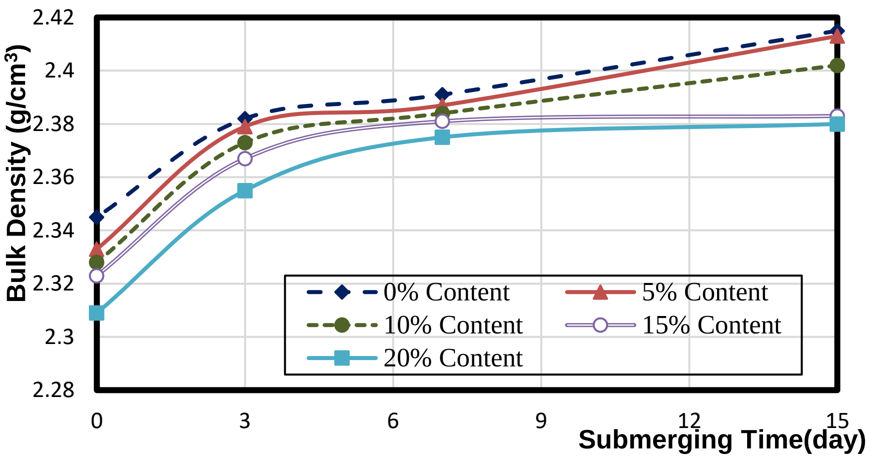

Fig.8. Effect of submerging time on bulk density for Addicrete PVS.

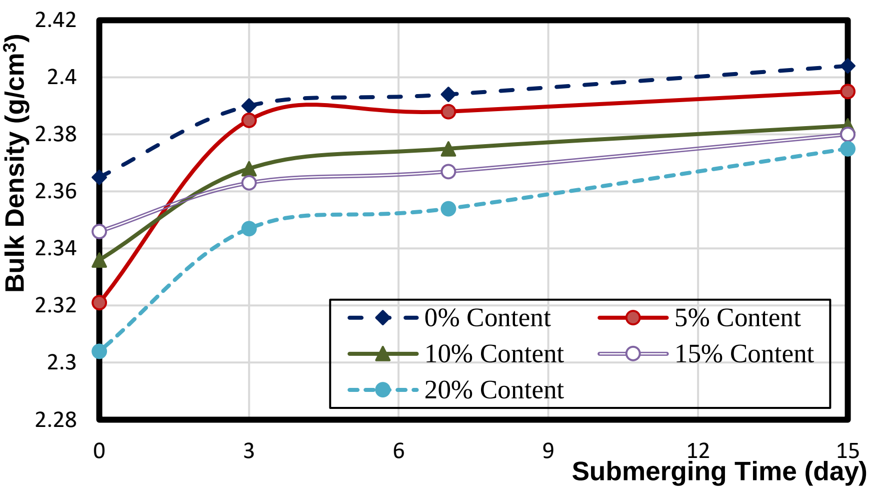

Fig.9. Effect of submerging time on bulk density for Adibond 65.

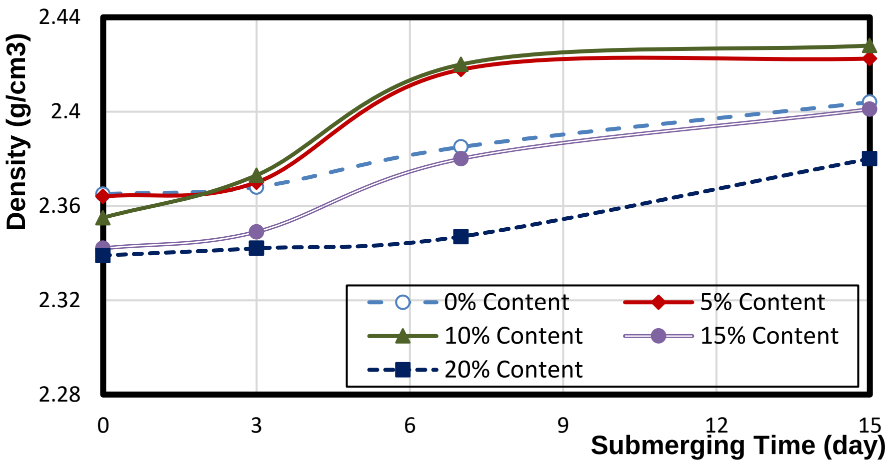

Fig.10. Effect of submerging time on bulk density for Silica Gel

4.1.4. Effect of type of additive on Marshall quotient

Figures (11, 12, and 13) show the relation between Marshall quotient for modified mixtures with Addicrete PVS, Adibond 65, and Silica Gel respectively at different contents versus submerging time. The value of Marshall quotient is decreased with the increase of submerging time for all tested molds as shown in the figures. This result may be due to the decreasing of Marshall stability value with the increase of submerging time. It is found that the value of the Marshall quotient is approximately equal to 60%, 59.9%, and 61.6% of the dried original compared to the sample modified with 10% content of Addicrete PVS, 5% of Adibond 65, and 10% of Silica Gel respectively after 15 days of submerging in wastewater. These results may come up because using the different additives increased the value of stability as shown in Figures (2,3 and 4).

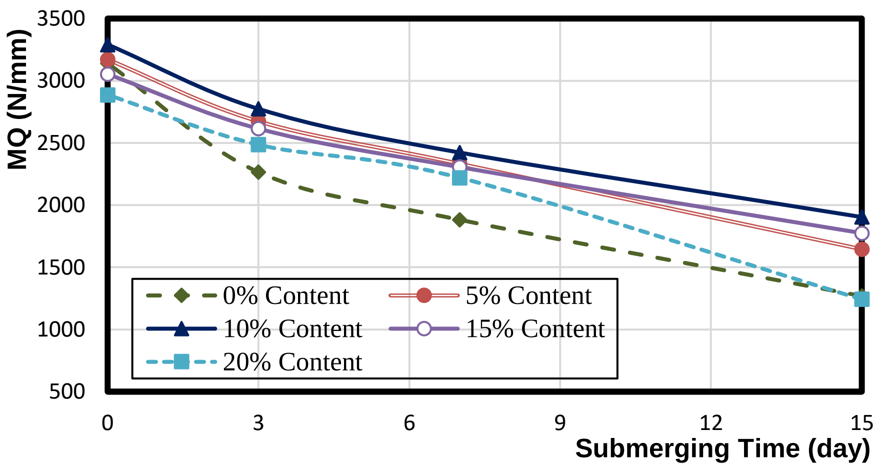

Fig.11. Effect of submerging time on Marshall quotient for Addicrete PVS

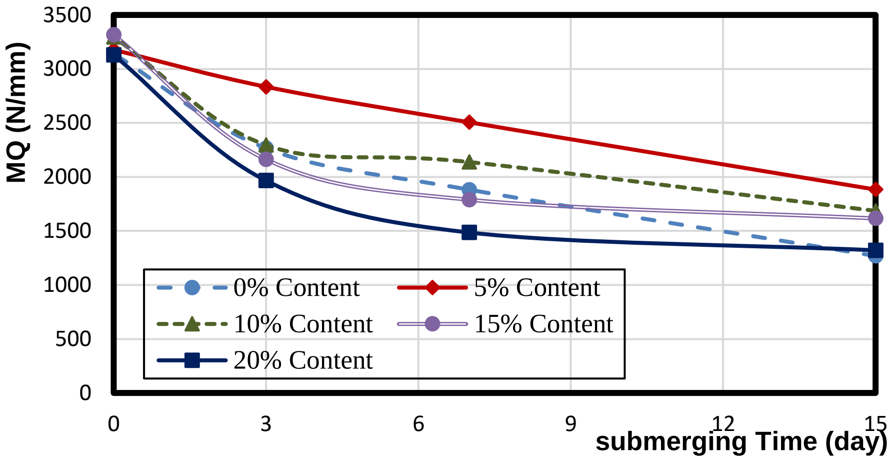

Fig.12. Effect of submerging time on Marshall quotient for Adibond 65

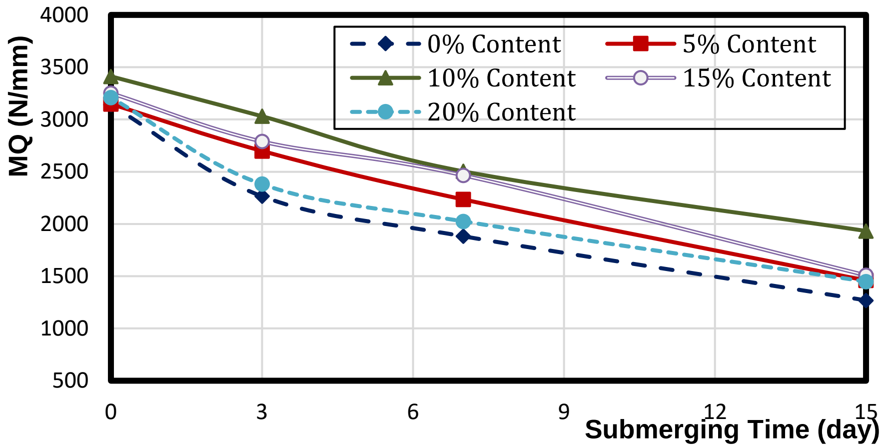

Fig.13. Effect of submerging time on Marshall quotient for Silica Gel

4.1.5. Effect of type of additive on Marshall stiffness

The relation between Marshall Stiffness of Addicrete PVS, Adibond 65, and Silica Gel respectively with different contents and submerging time was illustrated in Figures (14, 15, and 16). The value of Marshall stiffness is decreased with increasing time of submerging for all tested molds as shown in the figures. This result may be due to the decreasing of Marshall stability value with an increase of submerging time. It is found that the value of Marshall stability is approximately equal to 60.6%, 60.4%, and 61.6% of the dried original compared to the sample modified with 10% content of Addicrete PVS, 5% of Adibond 65, and 10% of Silica Gel respectively after 15 days of submerging in wastewater. These results may come up because using the different additives increased the value of stability as shown in Figures (2,3 and 4).

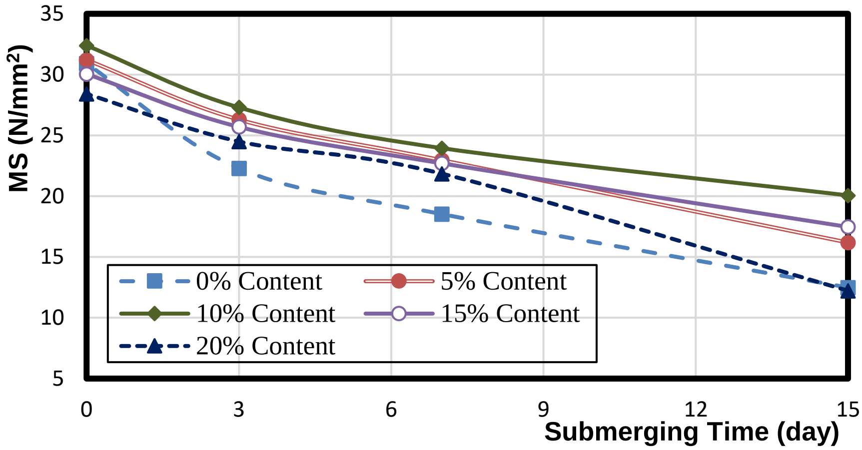

Fig.14. Effect of submerging time on Marshall stiffness for Addicrete PVS

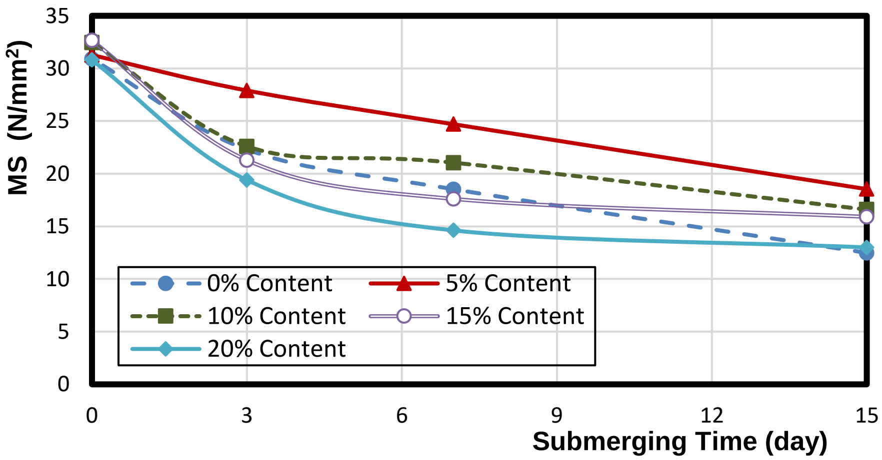

Fig.15. Effect of submerging time on Marshall stiffness for Adibond 65

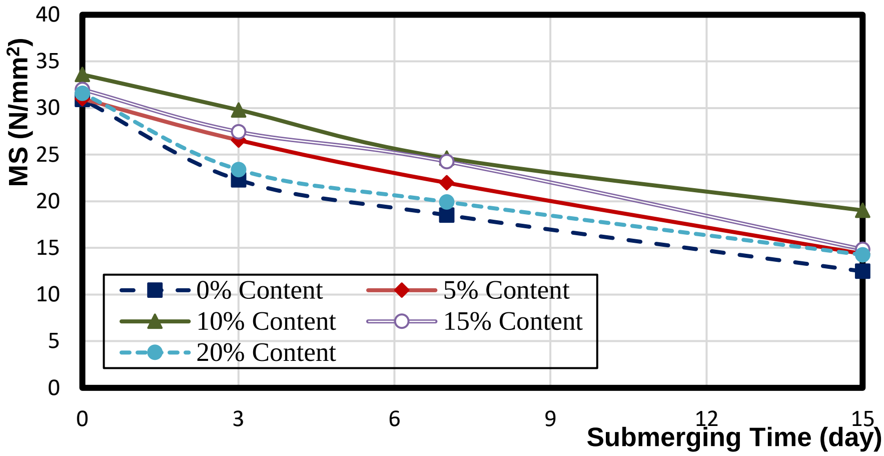

Fig.16. Effect of submerging time on Marshall stiffness for Silica Gel

4.2. Indirect tensile test results

4.2.1. Effect of type of additive on indirect tensile strength

The relation between indirect tensile strength (ITS)of modified mixtures with Addicrete PVS, Adibond 65, and Silica Gel at different contents versus submerging time were shown in Figures (17, 18, and 19) respectively. The value of ITS decreased with increasing time of submerging for all tested molds as shown in the figures. This result may be due to the decreasing of mixture ability to resist external loads due to the wastewater effect as shown from is low Marshall stability. It was found that the value of ITS is approximately equal to 95%, 94%, and 80% of the dried original compared to the sample modified with 10% content of Addicrete PVS, 5% of Adibond 65, and 10% of Silica Gel respectively after 15 days of submerging.

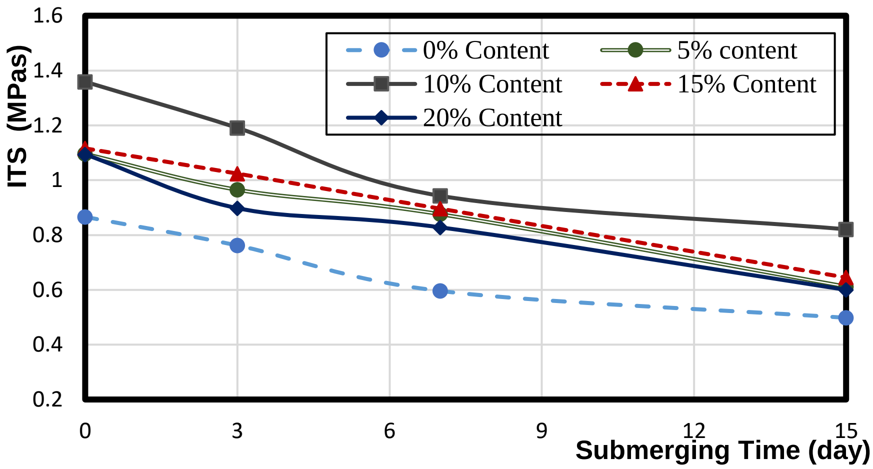

Fig.17. Effect of submerging time on ITS for Addicrete PVS.

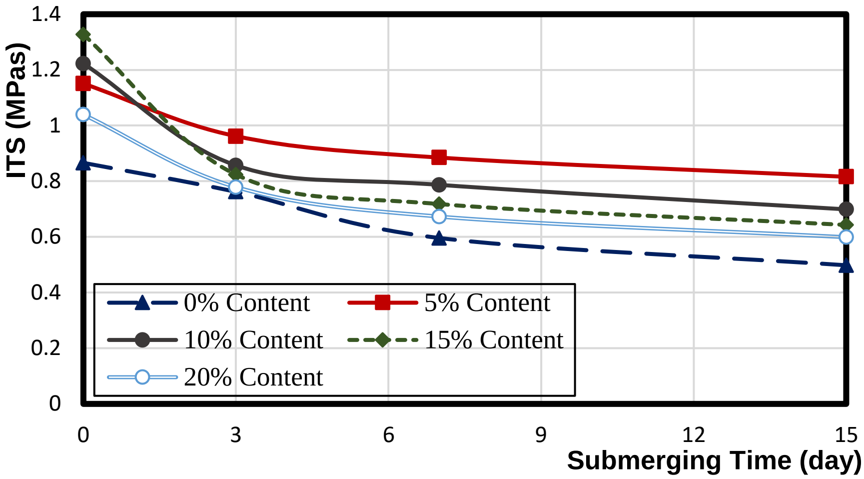

Fig.18. Effect of submerging time on ITS for Adibond 65

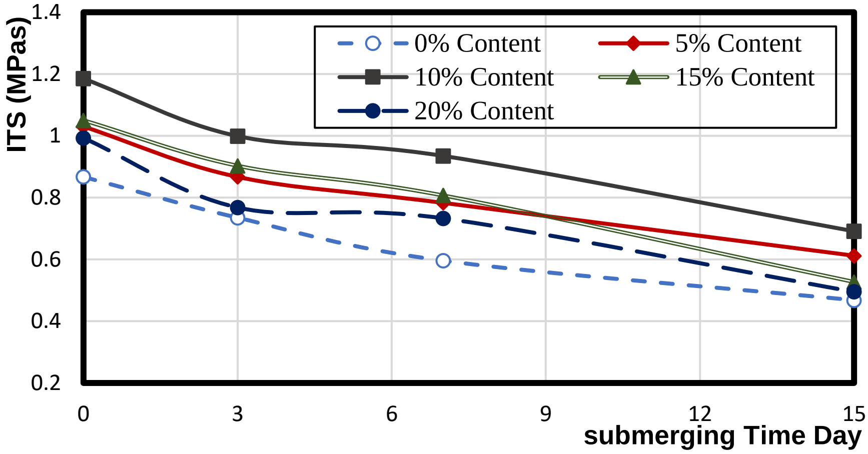

Fig.19. Effect of submerging time on ITS of Silica Gel.

4.2.2. Effect of type of additive on failure strain

The test results for failure strain for modified mixtures with Addicrete PVS, Adibond 65, and Silica Gel with different contents and immersing time were shown in Figures (20,21, and 22) respectively. The value of failure strain is increased as the time of immersing in wastewater increased for all tested molds as shown in the figures. The value of failure strain for modified mixtures was higher than the control mixture because adding different additives increase the value of indirect tensile strength (ITS) consequently increases the value of strain.

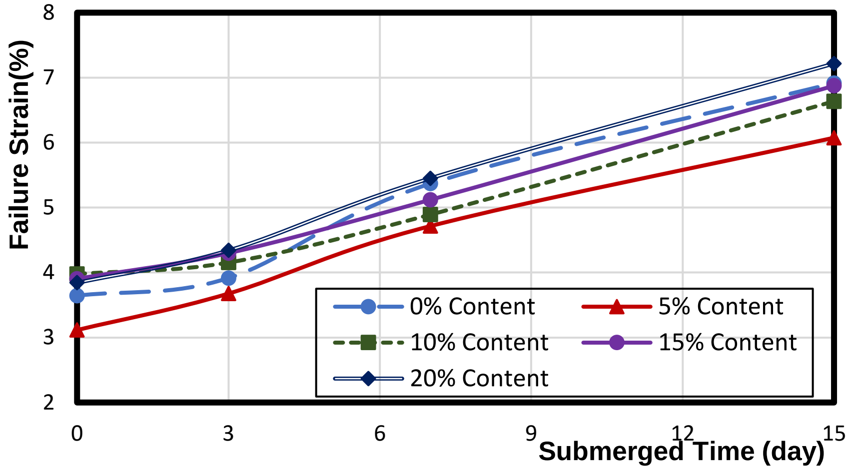

Fig.20. Effect of submerging time on failure strain for Addicrete PVS

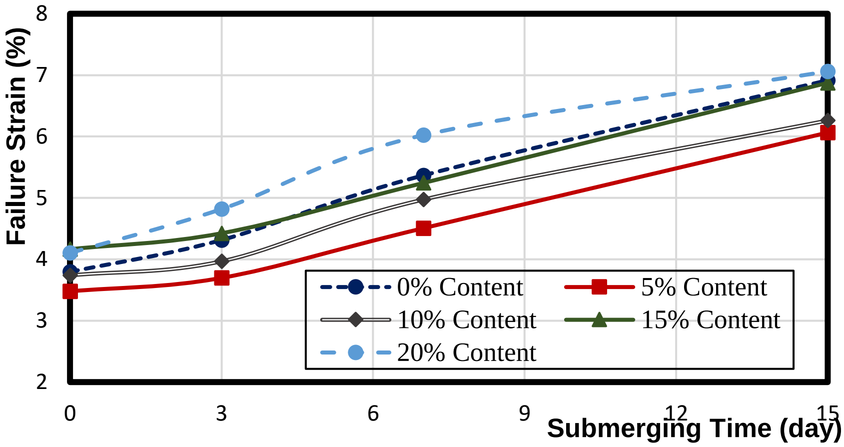

Fig.21. Effect of submerging time on failure strain for Adibond 65

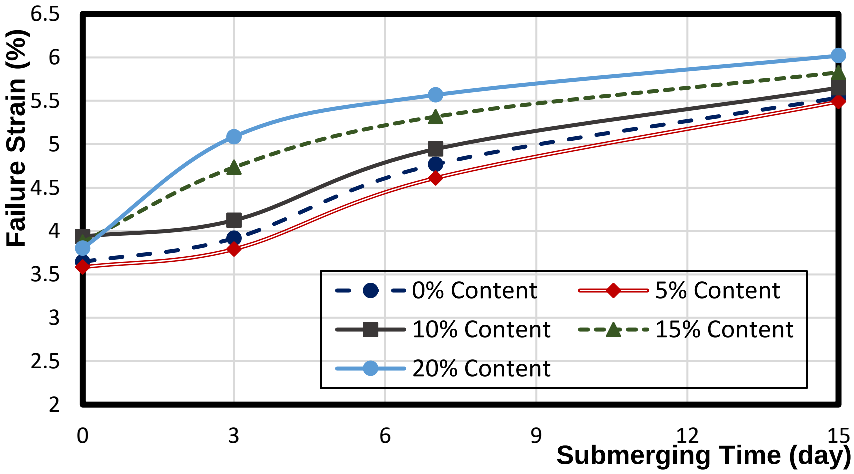

Fig.22. Effect of submerging time on failure strain for Silica Gel.

4.3. Comparison between types of additives

4.3.1. Marshall stability

The relation between Marshall stability and submerging time for different types of additives were illustrated in Figure 23. The results showed that the stability increased with using different types of additives comparing with the original mix. Using Addicrete PVS and Silica gel at 10% content increased the value of stability by 71.5% and 68.5% respectively. Also, using Adibond 65 at 5% increased the value by 54.1% It is clear from the results that using Addicrete PVS had the highest value of increasing in the stability.

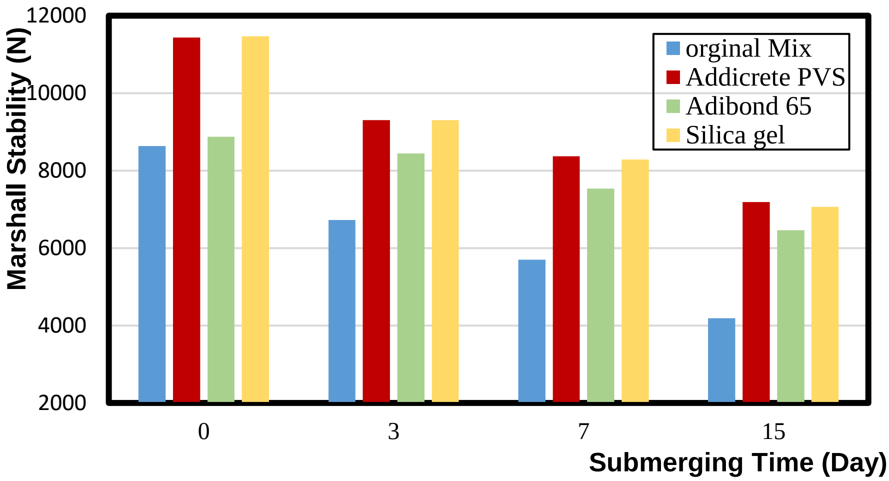

Fig.23. Marshall stability versus submerging time for different additives

4.3.2. Indirect tensile strength

Figure 24 illustrates the relationship between indirect tensile strength (ITS) and submerging time for different types of additives. The results showed that the stability increased with using different types of additives comparing with the original mix. Using Addicrete PVS and Silica gel at 10% content increased the value of ITS by 65% and 48.2% respectively. Also, using Adibond 65 at 5% increased the value by 60.6% It is clear from the results that using Addicrete PVS had the highest value of increasing in ITS.

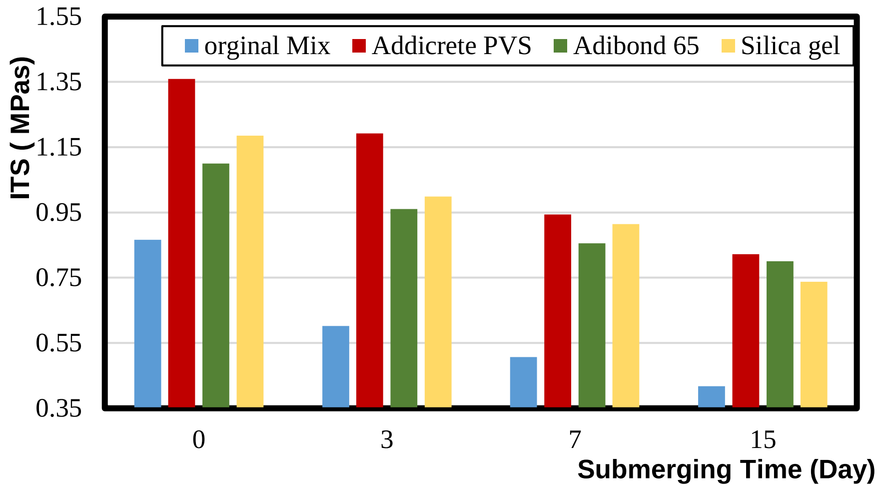

Fig.24. Indirect tensile strength (ITS) versus submerging time for different additives

4.3.3. Tensile strength ratio

the relationship between tensile strength ratio (TSR) and submerging time for different types of additives was shown in Figure 25. The results showed that the value of TSR deceased with increasing the submerging time in wastewater. Also, results revealed that using the different additives decreased the effect of wastewater on reduction the value of TSR comparing to the original mix.

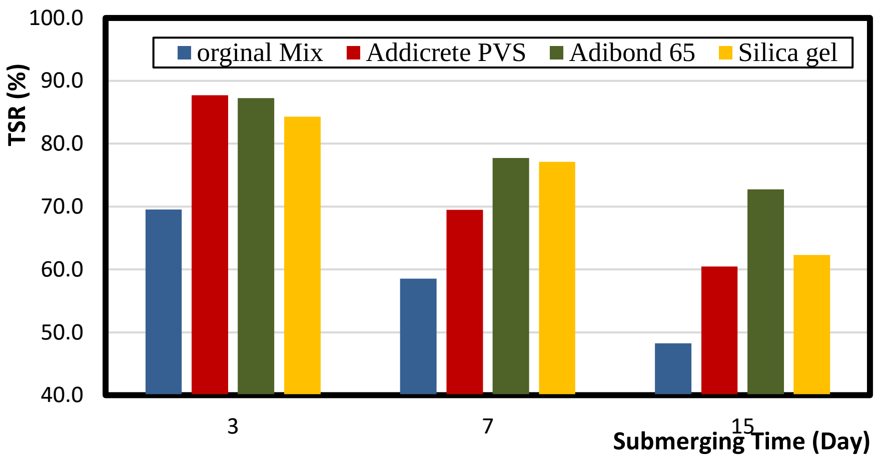

Fig.25. Tensile strength ratio (TSR) versus submerging time for different additives

5. Relation Between Indirect Tensile Strength and Stability for Addicrete PVS.

By using experimental results and the numerical analysis with Data fit Software an experimental model was performed for the prediction of the relation between Indirect tensile strength and Marshall stability for modified mixtures with Addicrete PVS at 10% content for a different submerging time as shown in Figure 26.

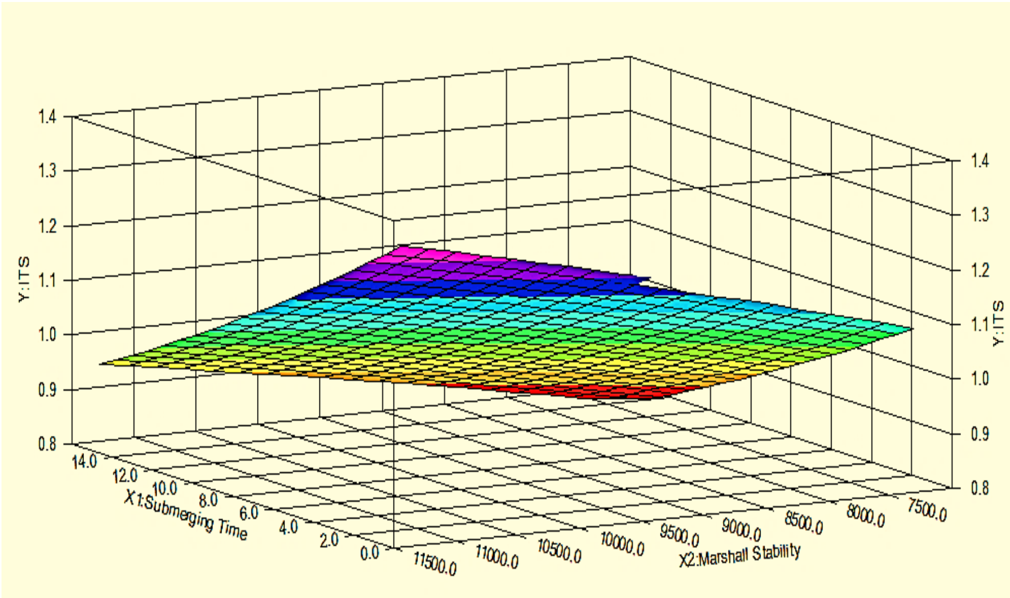

Fig.26. Model Plot

Mathematical model

$$Y = 2.5 * 10^{-2} * 0.9972^{x_1} * x_2^{0.427} \qquad R^2 = 94.8\% \ ....(1)$$

Where:

Y The Indirect Tensile Strength (ITS), MPas

X_1 Submerging Time in (days)

X_2 Marshall Stability (N)

6. Conclusions

It was noticed from the results that wastewater negatively affected the performance of all types of mixtures and this effect increased with the increase in the immersion time.

- The results showed that the best content for adding these additives to the mixture was 10% for using Addicrete PVS and Silica gel while it was 5% for using Adibond 65.
- Submerging the different mixtures in wastewater caused a loss in Marshall stability value. The value of the loss was 51.5% for the original sample awhile was 37.2% and 38.4% for Modified mixtures with Addicrte PVS and Silica gel at 10% content respectively. Also, the Marshall loss value was 27.3% whereas modified mixtures with Adibond 65 at 15% content.
- Utilizing Addicrete PVS and silica Gel at 10% content increased the stability value of the submerged mixture by 71.5% and 68.5% respectively while using Adibond 65 at 5% content increased the stability value by 54.1% in comparison to the control mix after 15 days of submerging in wastewater.
- The value of Marshall flow and failure strain of all mixtures increased with increasing submerging time.
- The indirect tensile strength value after 15 days of submerging the different mixtures was decreased by 42.5%, 39.6%, 27.3%, and 37.7% for original mix, modified mix with Addicrete PVS, Silica Gel at 10% content, and Adibond 65 at 5% content respectively.
- Utilizing Addicrete PVS and silica Gel at 10% content increased the indirect tensile strength value of the submerged mixture by 65% and 48.2% respectively while using Adibond 65 at 5% content increased the value by 60.6% in comparison to the control mix after 15 days of submerging in wastewater.
- The best material which reduced the wastewater effect to a minimum level was Addicrete PVS.

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تاثير استخدام الاضافات الكيميائية على اداء الرصف الاسفلتى المعرض لمياه الصرف الصحي

الملخص العربي:

من المعروف ان المياه هى العدو الاول للرصف الاسفلتى وتزداد خطورته عندما تكون المياه ناتج الصرف الصحي لما تحتويه من مواد عضوية واحماض. ان أحد التقنيات الشائعة المستخدمة فى تخفيف هذا الضرر هي استخدام الإضافات مع الاسفلت. يهدف هذا البحث الى دراسة مدى تاثير مياه الصرف الصحى على الخواص الميكانيكية للخلطات الإسفلتية التي تحتوي على اضافات كيميائية. تم استخدام ثلاث مواد كيميائية وهي اديكريت بي في اس، اديبوند ٦٥ وسيلكا جيل والتي تم اضافتها بنسب مختلفة وهي ٥٪ ،١٠٪، ١٥٪ و٢٠٪ من وزن البيتومين بالاضافة الى الخلطة الاصلية. تم خلط الأسفلت ٦٠/٧٠ مع عدة تراكيز لكل مادة مضافة باستخدام خلاط عالي القص عند درجة حرارة 130 درجة مئوية وبسرعة ٤٠٠٠ دورة في الدقيقة لمدة ٣٠ دقيقة. تم غمر الخلطة الاصلية والخلطات الإسفلتية المحتوية على اضافات كيميائية في مياه الصرف لعده ايام مثل 3،٧و ١٥ يوم. تم اجراء اختبارات مارشال واختبارات الشد الغير مباشر على هذه الخلطات المعرضه للصرف الصحى. على الرغم من ان مياه الصرف الصحى خفضت الخصائص الميكانيكية لكل الخلطات الا ان استخدام الاضافات قللت هذا التأثير بقيمة واضحة. ايضا اظهرت النتائج ان المحتوى الامثل لاضافة هذه المواد للخلطة هو ١٠٪ لكل من اديكريت بي في اس والسليكل جيل بينما كان ٥٪ لإضافة الاديبوند ٦٥. أفضل اضافة كانت مادة اديكريت بى فى اس بنسبة ١٠٪ من محتوى الاسفلت الامثل حيث انها حققت اعلى قيمه لكلا من ثبات مارشال، متانة مارشال ومقاومة الشد الغير مباشر.