Performance Evaluation of Modified Concrete Layer by Sodium Silicate in Rigid Highway Pavement

تقييم الأداء لطبقة الخرسانة المحسنة بسليكات الصوديوم في تبليط الطرق الجاسئة

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ABSTRACT

The using of conventional concrete mix in rigid pavement causes costly layer with high maintenance requirement . It is necessary to use additive materials in pavement construction as modifiers which could improves the performance of concrete layer .
The major objective of this research is to evaluate the mixing a locally additive on performance of concrete layer in rigid pavement by using sulfate-resisting cement (type V) produced in Iraq . The additive represented by soluble Sodium Silicate also known as " water glass " .
Concrete mixture specimen have been prepared with coarse aggregate of maximum size (50)mm and fine aggregate of maximum size (9.5)mm . Soluble Sodium Silicate has been used as an additive with the percentages (5 , 10 , 15) % by weight of cement . The performance of concrete mixture is evaluated using strength tests i.e (compressive and flexural) as well as thermal test (coefficient of thermal expansion) .
Results of using such modified concrete mixture show that compressive strength and modulus of rupture are decreased by (1.14 , 1.06) time at 7 days and increased by (1.17 , 1.16) time at 28 days respectively as compared with control mix . The results of coefficient of thermal expansion are decreased by (1.12) times at 28 days when compared with control mix . However, percent of 10% soluble Sodium Silicate in concrete mix shows better performance of concrete pavement corresponding for both strength and thermal properties . This percentage was adopted for all above mentioned comparison . The use of modified concrete mix has significant effect on the thickness design and joint spacing of main layer in rigid pavement .
Keywords: Rigid Pavement, Sodium Silicate, Additive Addition, Compressive Strength Test , Flexural Strength Test , Coefficient of Thermal Expansion Test .

ملخص البحث

إن استخدام خلطات خرسانية تقليدية في التبليط الصلد يسبب طبقات مكلفة ذات متطلبات صيانة مرتفعة .اذا من الضروري استخدام مضافات تؤدي الى تطوير اداء الطبقات الخرسانية .
ان الهدف الاساسي في البحث هو تقييم خلط مضاف محلي على اداء طبقات الخرسانة ضمن التبليط الصلد وباستخدام السمنت المقاوم للأملاح المنتج في العراق . والمضاف يمثل سليكات الصوديوم ويعرف ايضا ب " ماء الزجاج " .
تم اعداد نماذج الخلطات الخرسانية بركام خشن ذو مقاس اقصى 50 ملم وركام ناعم ذو مقاس اقصى 9.5 ملم وتم استخدام سليكات الصوديوم بنسب (5 ، 10 ، 15) % من وزن السمنت .
ان اداء الخلطات الخرسانية تم تقييمها بفحوصات المقاومة (الانضغاط والكسر) مع الفحص الحراري(معامل التمدد الحراري) .
اظهرت نتائج مقاومة الانضغاط ومعايير الكسر عند استخدام الخلطات الخرسانية المعدلة نقصان بنسبة (1.06، 1.14)مرة بعمر 7 ايام وزيادة بنسبة (1.17، 1.16) مرة بعمر 28 يوم عند مقارنتها بالخلطات القياسية . ان نسبة 10 % سليكات الصوديوم في الخلطة الخرسانية اشرت اداء احسن لطبقة الرصف لكل من خواص المقاومة والحرارة . وعليه فان تلك النسبة قد اعتمدت لجميع انواع المقارنات المذكورة في اعلاه .
ان استخدام الخلطات الخرسانيةالمعدلة له تاثيرفعال على تصميم السمك ومسافةالمفاصل في الطبقةالرئيسية للرصف الصلد .
كلمات البحث : التبليط الصلد، سليكات الصوديوم ، اضافة المضاف ، فحص مقاومة الانضغاط ، فحص مقاومة الانثناء ، فحص معامل التمدد الحراري .

Introduction:

Concrete roads play an important part in any nation's infrastructure. Their construction and maintenance, and the vehicles that travel over them, consume large amounts of energy. This energy use results in atmospheric emissions, the reduction of a non-renewable resource and other environmental impacts. Any reduction of the lifetime energy use associated with roadding, even if only by a small percentage, will, have significantly positive implications for sustainable development .

Concrete mixtures can be designed to provide a wide range of mechanical and durability properties to meet the design requirements of a structure . The compressive and flexural strengths of concrete are the most common performance measure used by engineer in designing building and other structures like concrete roads [1] .

Concrete expands when its temperature increases and contracts when its temperature decreases. The measure of how concrete changes in volume in response to temperature change is called the Coefficient of Thermal Expansion (CTE) of concrete, defined as the change in unit length per degree of temperature change. Which is one of the critical factors considered in the design of concrete pavements [2] .

(CTE) in concrete is the measure of how concrete changes in volume in response to changes in temperature. Once set, the thermal expansion and contraction of concrete is a function of cement content, aggregate type, temperature range and relative humidity [3] . The thermal expansion and contraction of a concrete pavement can have a significant effect on its performance and can cause joint lock-up and blowups. Thermal contraction can result in transverse cracking of slabs depending on the joint spacing. Thermal effects also impact slab bending and curling and when joints/edges are curled upwards, there do not have full contact with the base and are subject to cracking under traffic loading [3] . This could be particularly significant for long, thin slabs under heavy, frequent loading .

However, (CTE) is an important parameter that might affect the service life of concrete pavements. It controls joint opening, which affects load transfer efficiency, joint sealant performance, spalling, and even the potential for catastrophic failures such as blow ups. The extent of longitudinal and transverse cracking associated with thermal curling on jointed concrete pavements is believed to depend on CTE. For continuously reinforced concrete pavements the CTE has a strong effect on crack spacing and crack width [4] .

For survey asked agencies about their practice with respect to important individual material tests by category. The response for the primary concrete material properties that are used in concrete is shown in Table (1) .

Table (1): Current Practice for Portland Cement Concrete Testing [5]

Property	Number of Agencies Collecting Material Properties (out of 11)		
	Regularly	Sometimes	Never
Modulus of Elasticity	1	1	9
Flexural Strength	3	2	6
Coefficient of Thermal Expansion	2	1	8
Shrinkage	1	2	8
Thermal Conductivity	1	0	10
Heat Capacity	0	0	11

Researchers [6] , [7] explained that three are theories on how silicates act to improve the performance of concretes:

- SiO2 precipitating in the pores .
- Silicates forming an expansive gel similar to that formed in alkali silica reactions that fills the pores in the concrete by swelling .
- Silicates reacting with excess calcium present in the near surface region of the concrete to form relatively insoluble calcium-silicate hydrates .

The latter theory is currently the most accepted. In this way, theoretically, the pore blockers are products composed by silicate, which penetrate the superficial pores of the concrete and react with portlandite forming C-S-H. Sodium silicate is the mostly used silicate applied in this way .

Soluble sodium silicate, also known as " water glass" are utilized in several different aspects of the cement industry . For example, they act as set accelerators shotereting applications, they can be incorporated in to cementitious waste forms and they serve as moisture reducers in the wet kiln process of clinker production . Silicate solutions are very useful materials that can improve the durability of concrete when used properly [8] .

Sealing concrete with soluble Sodium Silicate may improve surface properties such as hardness, permeability, chemical durability, and abrasion resistance previously, such treated surface had not been characterized sufficiently to provide a complete understanding of how silicate improves concrete properties [9] .

Researchers [10] studied the effect of some liquid Additive on main mechanical properties of concrete and they concluded .

- The use of such Additive increased the Modulus of rupture value significantly while the compressive strength stay at the same level .
- The addition of such additives to concrete mix in fresh state cause an ideal effect on that mix by decrease in water cement ratio when comparing with control once and workability by ball-bearing phenomena which result from disperse effect of surface actives substances .
- Fabric selection of additive made more combination in concrete mix with concept similar to concrete reinforcement, by strength the side strains and decreased their effect while loading and by decreased the air content in various ages .

Materials :

The following article provide information on the material used in concrete mix .

Sulfate-resisting cement (Type V) commercially known (TASLUJA) produced in Iraq was used. Table (2) and (3) show the chemical composition and physical properties of cement used throughout this work respectively. Results indicate that the cement is conformed to Iraq specification (No.5/1984) .

Table (2) : Chemical composition and main compounds of cement *

Compound composition	Chemical composition	Percentage by weight	Limits of (IQS NO.5/1984)
Lime	CaO	63.33	-
Silica	SiO_2	21.84	-
Alumina	Al_2O_3	3.36	-
Iron oxide	Fe_2O_3	5.20	-
Sulphate	SO_3	2.20	2.5 %≤
Magnesia	MgO	2.31	5 %≤
Free lime	Free CaO	1.12	-
Loss on ignition	L.O.I	1.26	4 %≤
Insoluble residue	I.R.	1.29	1.5 %≤
Lime saturation factor	L.S.F.	0.88	0.66 – 1.02

Main compounds (Bogue' s equs)	Percent weight of cement	Limits of (IQS NO.5/1984)
Tricalcium silicate (C_3S)	51.0	-
Dicalcium silicate (C_2S)	24.14	-
Main compounds (Bogue' s equs)	Percentage by weight	Limits of (IQS NO.5/1984)
Tricalcium aluminate (C_3A)	0.1	3.5 %≤
Tetracalcium aluminoferrite (C_4AF)	15.82	-

* Chemical tests were conducted by the Environment Laboratory in University of Babylon

Table (3) : Physical properties of cement *

Physical properties	Test results	Limits of (IQS NO.5/1984)
Setting time (Vicat's Method) Initial, min Final, min	 125 230	 45 min≥ ≤ 600 min
Fineness (Blaine Method), m^2/ kg	320	45 m^2/ kg≥
Compressive strength, MPa 3 days 7 days	 19.0 27.0	 15, MPa≥ ≤ 23, MPa

***** Physical tests were conducted by the construction material Laboratory in University of Babylon

Natural sand from Najaf city, quarry of Wilat-Ali was used as a fine aggregate. Table (4) shows the sieve analysis of the fine aggregate. Results showed that the sand grading was within the requirements of the (IQS NO.45/1984), Table (5) illustrates the physical properties and sulfate content of the sand .

Table (4) : Sieve analysis of fine aggregate

Sieve size		PP %	(S.C.R.B, 2007) Specification
(in.)	(mm)		
⅜	9.5	100	100
No. 4	4.75	98	100-95
No. 16	1.18	77	80-45
No. 50	0.30	26	30-12
No. 100	0.15	3	10-2
No. 200	0.075	1	3-0

Table (5) : physical properties and sulfate content of the fine aggregate *

physical properties	Test results	Limits of (IQS NO.5/1984)
Specific gravity	2.61	-
Absorption	2%	-
Fineness modulus	2.56	-
Dry-Loss density (kg/m^3)	1593	-
Sulfate content	0.38%	0.5 %≤

***** Physical tests were conducted by the construction material Laboratory in University of Babylon

Rounded gravel of 50 mm maximum size was used as coarse aggregate. It was obtained from AL-Nebaee quarry. Table (6) shows that the grading of coarse aggregate is conform to the Iraqi specification (IQS NO.45/1984). The specific gravity, sulfate content, loss bulk density and absorption of coarse aggregate are listed in Table (7) .

Table (6) : Sieve analysis of coarse aggregate

Sieve size		PP %	(S.C.R.B, 2007) Specification
(in.)	(mm)		
2	50.0	100	100
½1	37.5	98	90-100
¾	19.0	65	35-70
⅜	9.5	17	10-30
No. 4	4.75	2	0-5

Table (7) : physical properties and sulfate content of the coarse aggregate

physical properties	Test results	Limits of (IQS NO.5/1984)
Specific gravity	2.65	-
Absorption	1%	-
Dry rodded density (kg/m^3)	1650	-
Sulfate content	0.04%	0.1 %≤

Ordinary tap water in Babylon University was used for both mixing and curing of concrete .

Liquid Sodium Silicate , known as water glass or liquid glass. This commercialized product was chosen because it is used for many purposes and is formed solely by sodium silicate. Different percentage of Liquid Sodium Silicate was investigated, (5, 10, 15)% by weight of cement . This additive is produced by two processes:

1. **Rotary Furnace Process:** The State-Of-The-Art Technology is used to manufacture sodium silicate by fusing pure silica sand with soda ash in rotary furnace at 1300oC, various SiO2 /Na2O ratios are produced. When the molt is cooled down a clear glass of sodium silicate is obtained, which varies from colorless to greenish blue in color is obtained. A premium product with exceptionally pure quality (maximum of 0.3% metal oxides) is produced .

   By using a steam pressure dissolver with in-line filtration, glass dissolves in exothermic reaction and gives an exceptionally clear solution with a long shelf life. Various grades of solution with ratio ranging from 2.0 to 3.3 combined with density ranging from 1.36 to 1.6 gm/cm3 and a viscosity ranging from 150 to 7500 CP are being currently manufactured .
2. **Hydrothermal Process:**Known as the"Wet Process"for the manufacture of silicates directly in solution form,where the silica from san leached out under pressure by concentrated caustic soda solution.This process lends itself to the production of crystalline silicates solution.The specific gravity,Viscosity and percent of Na_2O and SiO_2 of Liquid Sodium Silicate are listed in Table (8).

Table (8) : physical properties of the Liquid Sodium Silicate

Property	Liquid Sodium Silicate
Na_2O%	13.92
SiO_2 %	29.59
Specific Gravity	1.427
Viscosity at 30 ^{0}C (CST)	1848

Sample Preparation :

The mixing ratio (1 : 1.5 : 3) (cement : sand : gravel) by weight is adopted . Attended all of the sodium silicate solution, water, cement, sand and gravel weights required. Gravel was developed first in confusion and then sand and cement mixing operation, then added sodium silicate solution as a percentage by weight of cement after reducing the water content and added solution (water + sodium silicate) to dry materials in mixing and continue mixing for 120 seconds and then turn the mixture in the mixing basin borders, and to ensure that all material in the concrete mix for 30 seconds on the other .

All concrete mixes shall be proportioned by weighting and shall conform to the following strength and mix requirements:- [11]

Compressive Strength, 28 days : 30 MPA .
Water-Cement Ratio : 0.5 .
Cement Content per Cubic Meter : 436 Kg/m^3 .
Coarse Aggregate Content per Cubic Meter : 1309 Kg/m^3 .
Fine Aggregate Content per Cubic Meter : 655 Kg/m^3 .
Water Content per Cubic Meter : 218 Kg/m^3 .

Compressive Strength Test :

For compressive strength test 36 cubic specimens were casted with dimensions (150*150* 150 mm) according to B.S: (1881 : part 116: 1989) [12] **.** The compressive strength cubes were tested by using a standard testing machine with a capacity of (2000)kN. The loading was applied at a rate of 18 MPa per minute . The average of three cubes was adopted at each test, test was conducted at ages of (7 and 28)days. The compressive strength apparatus is shown in Plate (1) .

Plate (1) : Compressive strength apparatus

Modulus of Rupture Test :

The modulus of rupture were performed according to (ASTM C78-2002) [13] . Specimens were fabricated with dimensions (100*100*400 mm), by using flexural strength test machine of (2000)kN capacity. Figure (1) and plate (2) shows the setup of the test. The theoretical maximum tensile stresses that reached the bottom fiber of the tested beam is known as the modulus of rupture. The fracture occurs within the central one-third of the beam for all specimens, therefore the modulus of rupture was calculated using the following formula [14] :

MR = PL/bd2 ……….. (1)
Where :
MR: modulus of rupture (MPa) .
P: maximum applied load, (N).
L: effective span length (mm).
b: width of the specimen (mm).
d: depth of the specimen (mm).

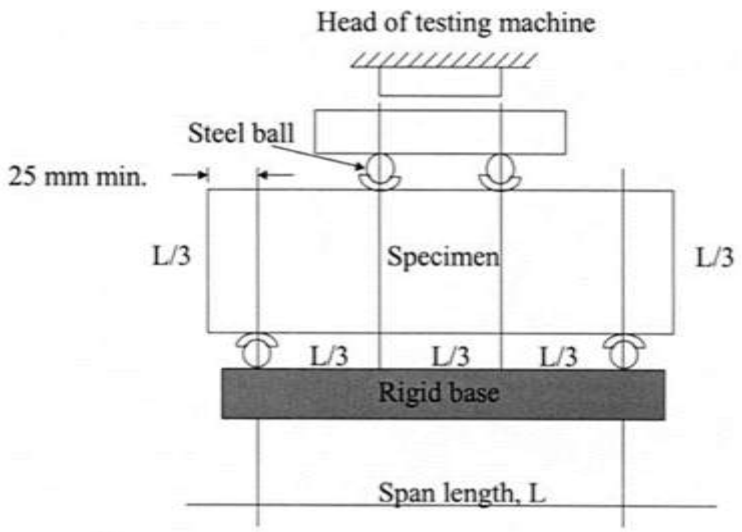

Figure (1) : Test for modulus of rupture

Plate (2) : shows the setup of the test

Linear coefficient of thermal expansion :

The linear coefficient of thermal expansion is calculated in accordance with AASHTO TP 60 [15] . The measuring apparatus is divided into three parts: measuring and carrying frames, water bath, and digital thermometers. The measuring frame is designed for a typical cylindrical specimen, and its height can be adjusted depending on the specimen heights. A precise dial gage graduated with (0.001) mm and total travel distance of (2.5 mm) is installed on the top of the frame to measure the length change of concrete specimen. A calibration specimen made with concrete material is used to calibrate the length change of the frame itself. During the calibration process, the calibration factor of the frame was measured and directly used for the calculation of concrete CTE. The water bath has a capacity of (70) liters and appropriate dimensions to place the measuring frame. A temperature probes is installed inside the water bath to measure water temperature continually. A carrying frame is used to control the vibration of the heating/ cooling circulator because its vibration can affect the measurement of the dial gage. Electronic digital caliper is used for height measurement. It has the following specifications:

- Measuring range from (0) up to (210) mm.
- Resolution of (0.01) mm.
- Accuracy of (±0.03) mm.

plate (3) shows the CTE measuring apparatus.

Plate (3): CTE measuring apparatus

A measurement frame with the dial gage attached is placed in the water bath and the bath is filled with water. Figure (2) give details of measuring frame.

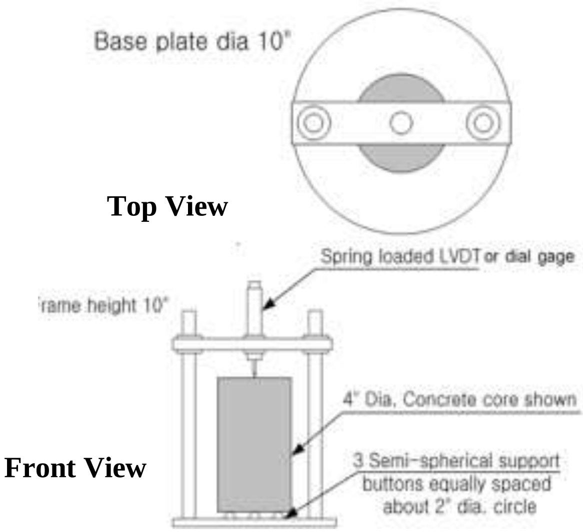

Figure (2) Schematic of a Measuring Frame (AASHTO TP 60 2004) [15]

The specimen is next placed in the controlled temperature bath, making sure that the lower end of the specimen is firmly seated against the support buttons, and that the dial gage tip is seated against the upper end of the specimen.

The CTE of one expansion or contraction test segment of a concrete specimen is calculated as follows (reported in microstrain / ^oC):

$$CTE = \frac{\Delta l_a}{l_a \times \Delta T} \quad \ldots\ldots\ldots.(2)$$

but, $\Delta l_a = \Delta l_m + \Delta l_f$ $\quad \ldots\ldots\ldots\ldots(3)$

Since the frame expands while the concrete specimen is expanding .

and, $\Delta l_f = C_f \times l_0 \times \Delta T$ $\quad \ldots\ldots\ldots\ldots..(4)$

where,

Δl_a = actual length change of specimen during temperature change, mm.

l_o = measured length of specimen at room temperature, mm.

ΔT = measured temperature change (average of three sensors), ^oC (increase = positive, decrease = negative).

Δl_m = measured length change of specimen during temperature change, mm (increase = positive, decrease = negative).

Δl_f = length change of measuring apparatus during temperature change, mm .

C_f = correction factor accounting for the change in length of the measuring apparatus with temperature, in /^oC. (The derivation for the correction factor is presented in section below).

The test result is the average of the two CTE values obtained from the two test segments (expansion and contraction) provided the two values are within (0.3 x 10^{-6} /^oC) of each other.

Consider the schematic CTE test frame shown in Figure (3). The test is used to determine a correction factor to account for expansion of the measuring apparatus during the test. The specimen should be composed of a material which is essentially linearly elastic, no corroding, non-oxidizing, and nonmagnetic, and should have a thermal coefficient as close as possible to that of concrete (304 stainless steel, which has a CTE of 17.3 x 10^{-6}/°C, is a suitable material). The reference material sample should also be of the same nominal dimensions as the test samples, so that no adjustment of the frame and/or the dial gage is necessary between calibration and testing.

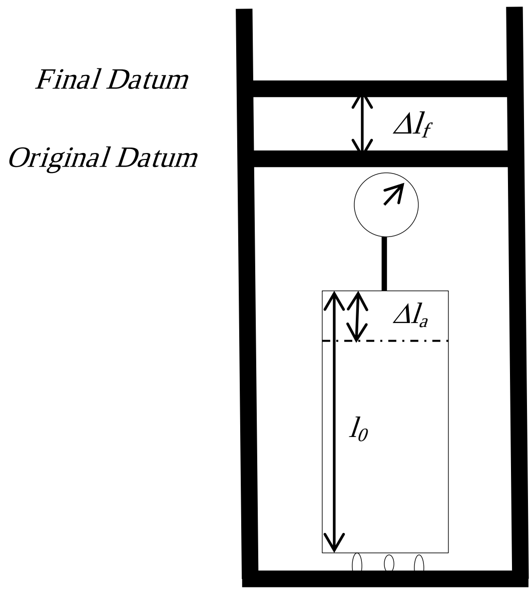

Figure (3): Schematic of the CTE test frame (Drawing not to Scale)

CTE of calibration specimen must be known. So that the following procedure is used to determine it:

- Measure concrete calibration specimen length at room temperature.
- The concrete calibration specimen is placed in a water bath with a temperature of ($10^oC\pm1$) for one hour.
- At the same time, testing frame is placed in the apparatus water bath and set at ($50^oC\pm1$).
- The calibration specimen then placed at the measuring frame and set the dial gage at zero. The frame in this case is expanded and the specimen contracted so that the specimen will be expanded and dial gage reading is recorded.
- Calculate CTE from equation (2).
- This procedure is repeated until the difference between two results are within (0.3) micro strain.

  Assuming that the length change of the apparatus varies linearly with temperature, the correction factor C_f *is* defined as:

$$C_f = \frac{\Delta l_f}{l_{cs} \times \Delta T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5)$$

where:

Δl_f = length change of the measuring apparatus during temperature change, mm .

l_{cs} = measured length of calibration specimen at room temperature, mm; and

ΔT = measured temperature change, °C (increase = positive, decrease = negative).

$$\Delta l_f = \Delta l_a - \Delta l_m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

where:

Δl_a = actual length change of calibration specimen during temperature change, mm (see Equation 3-13); and

Δl_m = measured length change of calibration specimen during temperature change, mm (increase = positive, decrease = negative),

$$\Delta l_a = l_{cs} \times \propto_c \times \Delta T \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

where:

$\propto_c$ = CTE of calibration specimen, °C (known).

Test Results and Discussions :

The major advantages of using Sodium Silicate as a liquid polymer as an additive in concrete are :

- Increase the workability of concrete through the resulting increase of the aerodynamic Although reducing the water content .
- Provide concrete production with little water content without affecting the other properties .
- Increase the compressive strength of concrete due to the high efficiency of the additive to reduce the water content in the concrete mixture .
- Reduce the cement content .
- Improve and increase the tensile strength of concrete .
- Reduce the absorption of concrete by reducing the water content .
- Increase the density of concrete .

Compressive Strength Test:-

Compressive, task characteristics and generally reflect the quality of concrete, design and sustainability, and is the main indicator for being easy measurement .

The compressive strength is one of the most important properties of hardened concrete. Table (9) and Figure (4) shown the average of the results of compressive strength test at 7 and 28 days gained from cubes. the results of control mix agree the Iraqi specification (section R10). While the results of Liquid Sodium Silicate modified mixtures indicate that the best content is 10% .

Liquid sodium silicate modified mixtures give a decrease in compressive strength at 7 days and an increase at (28) days compared with the control mix. The reduction in compressive strength at (7) days belongs to the chemical hydration between cement and liquid sodium silicate. While the increase in compressive strength at (28) days belongs to the sodium silicate works minimize distances, where the interaction of sodium silicate with cement be gel filled voids in the concrete. Because the voids in the concrete mixture is a small part of the total volume of concrete that have the opposite effect on resistance . This behavior is in agreement with reference [6]

Table (9) : Results of compressive strength

Type of Mixture	Age (day)	Compressive Strength (MPa)
(Control)	7	19.6
	28	32.8
5% Liquid Sodium Silicate	7	12.7
	28	33.6
10% Liquid Sodium Silicate	7	17.2
	28	38.4
15% Liquid Sodium Silicate	7	15.4
	28	35.9

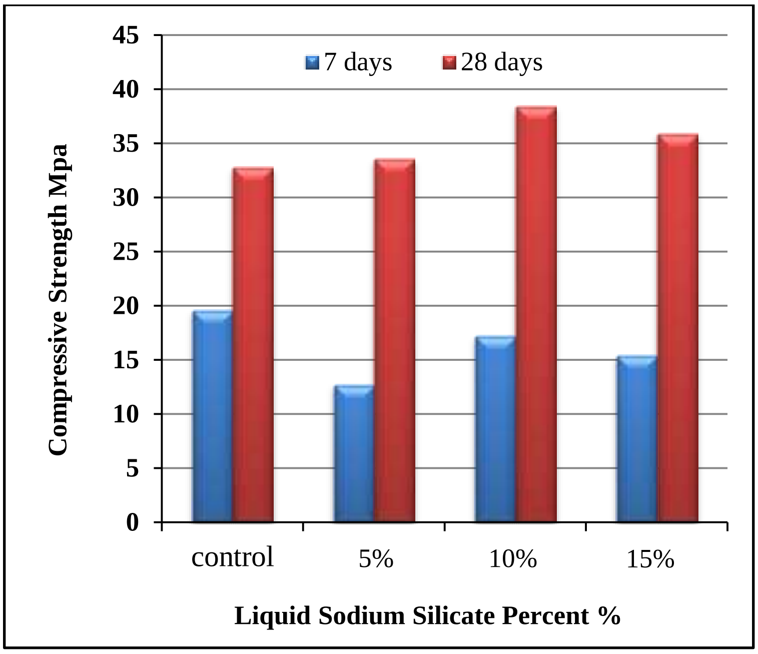

Figure (4) : Effect of Liquid Sodium Silicate percent on compressive strength

Modulus of Rupture Test:-

The flexural strength was measured by (100*100*400) mm normal concrete mix prisms of different percentage of liquid sodium silicate as shown in Table (10) and Figure (5) .

The results of Liquid Sodium Silicate modified mixtures indicate that the best content is 10% .

Liquid sodium silicate modified mixtures give a decrease in modulus of rupture at 7 days and an increase at (28) days compared with the reference mix. The reduction in compressive strength at (7) days belongs to the chemical hydration between cement and liquid sodium silicate. While the increase in modulus of rupture at (28) days belongs to liquid sodium silicate is chemically active material and their interactions with cement be gel to fill voids in the concrete, because sodium silicate are stickers of resolved a polymer dissolved .

Table (10) : Results of Modulus of Rupture

Type of Mixture	Age (day)	Modulus of Rupture (MPa)
(Control)	7	3.7
	28	5.0
5% Liquid Sodium Silicate	7	2.7
	28	5.3
10% Liquid Sodium Silicate	7	3.5
	28	5.8
15% Liquid Sodium Silicate	7	3.1
	28	5.4

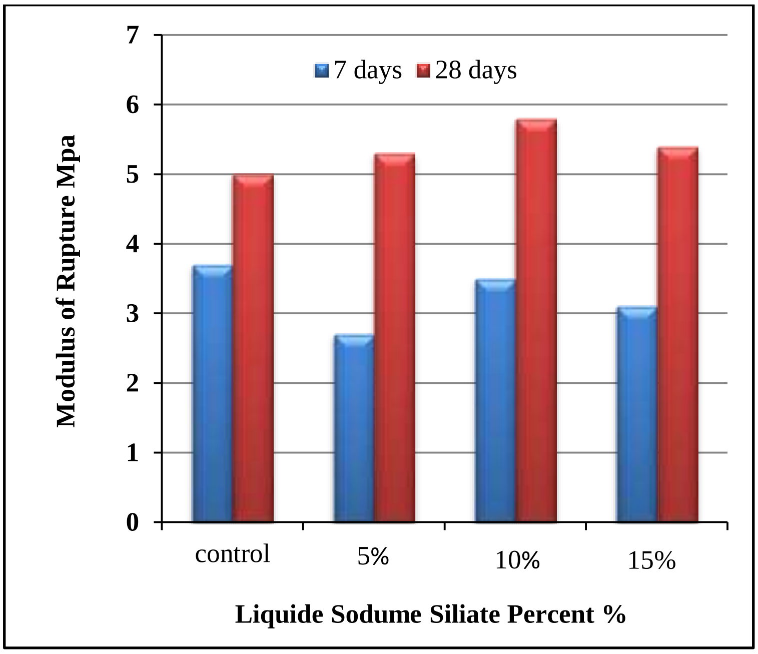

Figure (5) : Effect of liquid Sodium Silicate percent on modulus of rupture

Coefficient of Thermal Expansion Test (CTE) :

The magnitude of CTE is important in determining the amount of joint movement, slab length and joint sealant reservoir design. The selection of CTE in the design process have influence on pavement performance in the following ways:

Table (11): Influence of CTE on Pavement Performance [16]

Role of CTE	Pavement Distress
High CTE can potentially induce axial movement. This axial movement if restrained by slab-friction can lead to cracking	Premature cracking due to excessive longitudinal slab movement
High curling stresses due to high temperature gradients and CTE.	Mid-panel cracking
Higher corner deflections due to negative curling-which is a function of temperature gradients and CTE.	Faulting and corner cracking
Failure of joint sealant due to joint opening and closing.	Joint spalling
The magnitude of CTE determines the closeness and width of cracks and in turn impacts the load transfer efficiency of the crack.	Crack spacing and width in continuously reinforced concrete pavements (CRCP)

The CTE was measured by (100 × 200) mm normal concrete cylinder and different percentage of Sodium Silicate as shown in Table (12) and Figure (6) .

Water glass modified mixtures give a decrease in CTE for both 5% and 10 % percentage and then increase for 15% percentage. The decrease belongs to Sodium Silicate reduce the mobility of water in cement by forming hydrate gel without the occurrence of significant free water therefore, the thermal conductivity significantly decrease with a reduction in moisture content and cause the CTE to decrease too. A decrease in CTE has been found to significantly affect and decrease the possibility of cracking, faulting, spalling, and the roughness of jointed plain concrete pavement and the stresses induced by the concrete expansion and contraction with temperature changes result in transverse cracking, faulting, and joint spalling. While the increment for 15% percentage due to opposite effect of reaction in concrete mix and cement hydration with high percentage of water glass . This behavior is in agreement with principles in reference [17,18] . CTE values greater than 10.8 /°C results in large percentages of transverse cracking and thus, decreasing the design life of the pavement. The CTE affects the following aspects of pavement performance [19] :

- Early-age or premature random cracking if the excessive longitudinal slab movement (i.e., movement in the direction of traffic) caused by high CTE concrete is resisted by restraint forces (e.g., slab–base friction);
- Higher midpanel transverse and longitudinal fatigue cracking caused by higher curling stresses;
- Higher amounts of faulting caused by a greater loss of slab support at the time of construction (i.e., initial slab lift up during daytime construction), larger joint openings during adverse seasons, and greater corner deflections from curling;
- Joint spalling caused by failures of joint sealant as a result of excessive joint opening and closing; and
- Crack spacing and, more important, crack width in continuously reinforced concrete pavements over its entire design life (this factor has a major effect on the crack load transfer efficiency and hence punch-out).

Table (12): Results of coefficient of thermal expansion at 28days age

Type of mixture	Coefficient of thermal expansion (CTE) 10^{-6} /°C
(Control)	10.41
5% Liquid Sodium Silicate	10.11
10% Liquid Sodium Silicate	9.30
15% Liquid Sodium Silicate	13.50

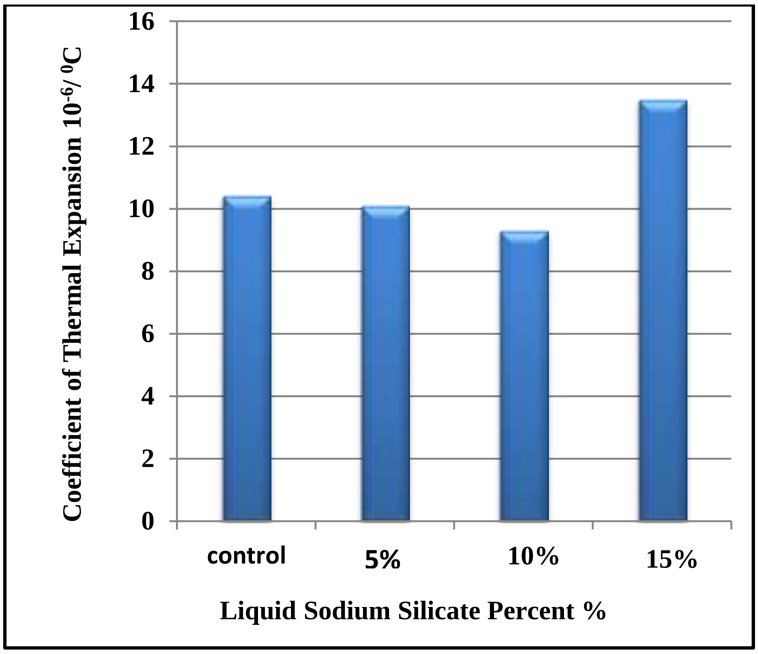

Figure (6) : Effect of liquid Sodium Silicate percent on coefficient of thermal expansion for samples aged 28 days

Effect of Concrete Modification by Sodium Silicate on Design of Rigid Pavement:

Rigid pavement consists of a Portland cement concrete slab with thickness (h) resting on subbase layer. The load carrying capacity is desired for the beam action of the slab because the modulus of elasticity of concrete is much higher than that of the subgrade or subbase materials. Therefore the variations in subgrade soil strength have a little significance up on the structure capacity of the pavement and for the same reason, the subbase layer under rigid highway pavement are used mainly for the control of pumping and not to improve the structure capacity [20] .

The monograph has a wide range in lines of flexural strength (MR). This design chart is governed the thickness of rigid pavement slab in the AASHTO Guide 1993 [21] . Table (13) shows a comparison which is based on layer thickness, between 10% Sodium Silicate modified concrete mixtures and normal vibrated mixtures . The thickness design results indicate that the modified concrete mixtures containing 10% Sodium Silicate render the slab concrete thickness of rigid pavement less than using normal vibrated mixtures . However, the increase of MR gives less thickness, as a result % of steel reinforcement became higher and the weight of one square of dimensions for concrete slab (according to requirements of joint spacing in AASHTO-93) is lower and then joint spacing will be higher.

Table (13) : Calculated thickness values of concrete slab for control and modified mix

Type of concrete mix	$W_{t\,18} \times 10^3$	K (pci)	MR (psi)	h (in)
Control mix	4000	200	725	7.5
`10% Sodium Silicate mix	4000	200	841	6.6

Conclusion :

Based on the test results obtained from the experimental works, the following conclusions can be drawn:

- The results of control mix agree with the Iraqi specification (section R10) in compressive strength test .
- The results of Liquid Sodium Silicate modified mixtures indicate that the best content is 10% in strength and thermal properties .
- Liquid sodium silicate modified concrete mixtures give a decrease in compressive strength by (1.14) time at 7 days and an increase of (1.17) time at (28) days compared with the controlled ones.
- Liquid sodium silicate modified concrete mixtures give a decrease in modulus of rupture by (1.06) time at 7 days and an increase of (1.16) time at (28) days when compared with the control ones.
- Liquid Sodium Silicate of modified concrete mixtures give a decrease in coefficient of thermal expansion by (1.12) times for samples aged 28 days when compared with controlled ones.
- The concrete mixture with higher compressive strength generally showed lower CTE values .
- The results presented in this work strongly suggest that longer lasting concrete pavements can be expected in the future if low CTE is specified which would decrease in construction cost and CTE should be considered by highway agencies and designers as one simple factor that could reduce cracking over the life of jointed concrete pavements .
- Modified concrete mix with 10% water glass render the layer thickness with decrease about (1.14) times than control mix , lead to decrease in initial construction cost .

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