International Science and Technology Journal
المجلة الدولية للعلوم والتقنية
Volume 39 العدد
Part 1 المجلد
المجلة الدولية للعلوم والتقنية
International Science and Technology Journal
ISTJ

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http://www.doi.org/10.62341/istj-vol39-1-ar26

Received	**2026/07/12**	**تم استلام الورقة العلمية في**
Accepted	**2026/08/04**	**تم قبول الورقة العلمية في**
Published	**2026/08/05**	**تم نشر الورقة العلمية في**

Study on some mechanical and chemical properties of rebar and the effect of water used in ready-mix cement concrete on its corrosion

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Abstract:
Using of rebar in the construction with growing demand for ready-mixed concrete, it was needed to shed lights on some mechanical and chemical properties. For this, tests including tensile strength, bending, and chemical analysis were conducted on random samples of two types of rebar, TS-4 and TS-40. In addition, chemical analyses were performed on water samples that collected from different of three ready-mixed concrete plants named (C, D, and E). Also, corrosion tests were carried out on that both types of rebar, for each type, 18 samples were selected and divided for two types of corrosion test. In the first test, the samples of rebar were immersed for six weeks in the that water samples, the average value of weight loss was recorded every two weeks, after that the samples were returned to the same medium. In the second test, the samples were immersed for six consecutive weeks, then removed, and the average value of weight loss was recorded. The results indicated that the TS-4 has a higher carbon content compared to ST-40, with a tensile-to-yield strength ratio around 1.82, also observed the Water samples for chemical analyses test values within international standards. Corrosion tests showed close weight loss values for both types.

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However, increased the corrosion ratio was observed in the low-carbon TS-40 type, when exposed to water of sample (E) this due to increased the Total Dissolved Solids (TDS) value, which lead to raise the electrical conductivity, lead to increased corrosion ratio.
Keywords: rebar, ready-mixed concrete, tensile strength test, chloride water test, Total Dissolved Solids (TDS), corrosion.

دراسة بعض الخصائص الميكانيكية والكيميائية لقضبان حديد التسليح وتأثير المياه المستخدمة في الخرسانة الأسمنتية الجاهزة على تآكله

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الملخص:

استخدام حديد التسليح في البناء وتزايد الطلب على استعمال الخرسانات الاسمنتية الجاهزة، برزت الحاجة إلى تسليط الضوء على بعض الخصائص الميكانيكية والكيميائية لهما. وذلك بأجراء الاختبارات على عينتين من حديد التسليح TS-4 & TS-40 حيث اخذت عينات عشوائية منهما اجريت عليها اختبار الشد والحني والتحليل الكيميائي ايضا اخذت عينات من المياه المستعملة في الخرسانات الأسمنتية من ثلاث محطات للخرسانة الجاهزة (C,D,E) واجرى التحليل الكيميائي لها, ثم اجراء اختبار التآكل للنوعين من حديد التسليح TS-4&TS-40 بأخذ 18 عينة من كل نوع قسمت الى نوعين من اختبار التآكل حيث كان الاختبار الاول بوضعها لمدة ستة أسابيع في عينات المياه(C,D,E) واخذ متوسط قراءة الفقد في الوزن للعينات كل أسبوعين ثم رجعت الى نفس الوسط والاختبار الثاني بوضعها في نفس عينات المياه لمدة ستة أسابيع متصلة ثم إخراجها وتسجيل متوسط فقد الوزن للعينات حيث اظهرت نتائج الاختبارات ان النوع TS-4 يحتوى على نسبة كربون اعلى وكانت نسبة مقاومة الشد الى مقاومة الخضوع تبلغ

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حوالي 1.82 كما أظهرت النتائج لعينات المياه انها من ضمن المواصفات العالمية واختبار التآكل الذى اجرى على العينات للنوعين أن كلا النوعين لهما قيم متقاربة لفقد الوزن كما لوحظ زيادة معدلات التآكل في النوع منخفض الكربون TS–40 المعرض لماء العينة E، نتيجةً لزيادة قيمة إجمالي المواد الصلبة الذائبة (TDS) مما أدي إلى زيادة الموصلية الكهربائية، وبالتالي زيادة معدلات التآكل.

الكلمات المفتاحية: حديد التسليح، الخرسانة الجاهزة اختبار مقاومة لشد، اختبار الكلورايدفى الماء، التآكل

1. Introduction

rebar is considered as one of the most important materials used in building and construction work, and it plays a vital role in enhancing the resistance of concrete, which is a strong material in resisting compression but weak in resisting tension[1][2] rebar structures was better able to withstand the excessive loads resulting from different uses, or earthquakes, winds and vibrations [2]. In use of rebar, the more strong and sustainable structures can be achieved, with less need for costly periodic maintenance[3][4].

Ordinary concrete resists compression well but is weak in tensile strength, so rebar was used to withstand the tensile forces for structural elements such as beams, columns and roofs are subjected[2]. Metal cracking is a result of mechanical stress combined with a corrosive environment [5]rebar works to bind the components of the concrete structure together, providing a high degree of cohesion and resistance to cracking and separation[6]

Corrosion of rebar is one of the most serious problems which are facing reinforced concrete structures. It leads to deterioration of structural performance, loss of strength and reduced lifespan, necessitating regular maintenance and costly repairs[7][8][9]. This type of corrosion causes deterioration of the bonds between the steel, concrete and the formation of cracks and voids due to the increased volume of corrosion by products, which exert pressure on the surrounding concrete[10][5]. This weakens the structure's ability to loads. Corrosion in the reinforcing steel occurs in successive stages, beginning with suitable conditions such as Moisture, oxygen

and corrosive substances. Oxidation then begins, forming layers of rust on the rebar surface. [11][12] Chlorides from external sources such as seawater, or from salt deicing materials, penetrate through the pores of the concrete and break down the alkaline surface protective layer around the reinforcing steel, thus beginning corrosion due to the apparition of chlorides that penetrate the concrete and cause the protective layer on the rebar to break down[13][8]. The existence of both oxygen and water is the essential condition for rebars corrosion. If the concrete allows these elements to easily penetrate (for example, due to high porosity or cracks), the rebar begins to corrode [2].

Due to its widely use of rebar in the building with the urban development in the field of construction and architecture in our country, in addition the use of ready-mix cement concrete, so that an important to understand the effects of the surrounding and medium on these rebars during the building construction. Therefore, this study aims to shed lights on the some of the mechanical and chemical properties of rebars, specifically their strength, load resistance, and the effect of corrosion when that water used in concrete mixes, by conducted some that experiments on the two types of rebar which are produce at the Misrata Iron Steel Plant that named TS-4 and TS-40.

2.Methodology:

Six random samples of rebar were collecting that diameter equal 20mm from the Misrata Iron Steel Plant, (three bars of rebar from the old plant called "TS_4" and another three bars of rebar from the new plant called "TS_40") all samples as iron that were used in reinforcement or construction.

Moreover, water samples were randomly selected from three ready-mixed concrete plants. The samples which were intended for used in the production of ready-mixed concrete were randomly obtained from the mixing locations directly, in order to perform chemical analysis tests as well as to determine the effect of rebar corrosion irrespective of the sources from they were obtained. They were classified as C, D and E are depending on their respective ready-mixed concrete plants, the laboratory measurements and analyses

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for this study were conducted in the Libyan Iron and Steel Company laboratories.

3. Equipment and methods Experimental:

This section will present the laboratory equipment and methods used to evaluate the mechanical and chemical properties bars of rebar samples, as well as to affect their corrosion rates with water. This equipment includes the following:

3.1. Tensile test:

It is one of the basic mechanical tests performed on samples of rebar to determine its mechanical properties under the influence of continuous tensile or pulling force until it breaks that Samples of rebar 500 mm in length, was taken and placed in a tensile testing equipment. The equipment began to gradually stretch the sample from both ends, the force and length were recorded moment by moment until the sample had broken, fig1 shows the results. Tensile tests were conducted by Hydraulic universal testing machine model DI-CP\V4, Capcity1200KN leioa,Bizkaia,Spain figure1 shows Equipment

Figure:1. Hydraulic universal testing machine

3.2. Bend test:

The quality of the metal, its flexibility (appearance of micro-flaws, cracks or frailty is exposed), measures how bending angle at a

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precise degree can make rebar to withstand fracture and failure. This sample bars were taken and tested. The rebar was mounted on a testing machine at an angle ($75° < \theta \leq 85°$) fig 2 shows the Equipment test used bending testing machine model DBH-20T Leioa, Bizkaia,Spain.

Figure:2 bending testing machine

3.3. Chemical analysis of rebar:
chemical test conducted on that samples of rebar, specialized equipment was used to analyze the chemical composition of the rebar and observed the proportions of various elements present, conforms to standard specifications and to guarantee its quality and durability using the rebar analyzer available in the laboratory.

3.4. A chloride water test:
To find (Cl^-) chloride value, performed the test on the samples by following procedure, where washed the test beaker by distilled water then fill in the beaker test by 10 ml from the sample of water, reset the device, add the chloride reagent, then wait two minutes for it to dissolve, Returned the beaker to the device that reading directly appeared, Chloride ion (Cl^-) concentrations were measured in mg/L using the chloride analyzer by palintest chlorometer fig 3 shows the Equipment.

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Figure 3: palintest chlorometer

3.5. Chemical analysis of water:

performed chemical analysis test on that samples (C, D and E) of water which obtained from the mixing locations directly to find the values of Total Dissolved Solids (TDS) Conductivity (CON), Potential of Hydrogen (PH) by preparing the device and that samples washed by the electrode with distilled water then Placed the electrode in the sample of water then recorded that result appear on the device, the measured conducted by Electrical conductivity meter JENWAY 4510 and PH Meter JENWAY 3520 and Total Dissolved Solids (TDS) were estimated based on conductivity fig 4 shows the Equipment.

Figure:4 Electrical conductivity meter and PH Meter

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3.6. Corrosion test procedure:

The samples were prepared from six bars of rebar, three from each type for both TS-4 &TS-40, each one formed to diameter of 17 mm, then cut into six pieces, each sample was 30 mm along, the total of pieces 36 samples then observed the effect of water that collected about them.

The total surface area of each piece of sample was used that formula for determine area of a cylinder: $r^2\pi + rh^2\pi$ where that samples weight by used an accuracy balance with an accuracy of 0.001

3.7. Samples preparation for corrosion test:

The bars of rebar samples were divided into two sections as following:

Section 1: This section contains eighteen samples of rebar left only two weeks in that samples of water (C, D, E) after that removed from the water, then the surfaces cleaned by the soft cotton textile to remove any rust and average weight loss recorded, then returned again to medium, that total period six weeks fig 7 shows the results.

Section 2: This section contained eighteen samples that left for six weeks period in that samples of water (C, D, E) after that removed from water and the surface cleaned by piece of the soft cotton textile to remove any rust then weighed, the measurements **samples for both types of rebar** and initial weights that used for corrosion tests are shown in tables (1-4).

Table 1: measurements samples of rebar for TS_4

No Bar	Smp	long mm	diameter mm	weight gm	Total area mm^2
1	A1	30.0	17.1	51.710	2070.95
	A2	30.5	17.2	53.391	2112.78
	A3	30.2	17.2	52.531	2096.57
2	A4	30.4	17.7	57.088	2182.54
	A5	30.5	17.8	57.233	2203.26
	A6	29.3	17.9	55.509	2150.96
3	A7	30.5	17.2	53.351	2112.78
	A8	29.8	17.3	51.825	2089.74
	A9	30.4	17.1	53.714	2092.44

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Table 2: measurements samples of rebar for TS_40

Bar No	Smp	long mm	diameter mm	weight gm	Total area mm^2
1	B10	29.2	17.4	50.357	2071.75
	B11	31.1	17.5	56.969	2190.86
	B12	30.0	17.4	54.921	2115.48
2	B13	29.8	17.3	53.846	2089.74
	B14	29.7	17.5	54.480	2113.89
	B15	29.9	17.7	54.757	2154.73
3	B16	32.0	17.1	54.723	2178.39
	B17	29.2	17.4	50.350	2071.75
	B18	29.8	17.1	51.270	2060.20

Table 3: measurements samples of rebar for TS-4

Bar No	Smp	long mm	diameter mm	weight gm	Total area mm^2
1	A19	30.4	17.2	53.392	2107.38
	A20	30.2	17.2	53.293	2096.57
	A21	30.2	17.2	52.835	2096.57
2	A22	30.0	17.8	56.481	2175.30
	A23	29.6	17.9	55.471	2167.84
	A24	31.8	17.7	58.436	2260.39
3	A25	30.1	17.2	53.112	2091.16
	A26	30.2	17.2	53.029	2096.57
	A27	29.9	17.2	52.807	2080.36

Table 4: measurements samples of rebar for TS-40

Bar No	Smp	long mm	diameter mm	weight gm	Total area mm^2
1	B28	31.0	17.5	56.118	2185.37
	B29	30.6	17.5	56.231	2163.37
	B30	30.6	17.4	55.342	2148.28
2	B31	30.1	17.5	54.815	2135.89
	B32	30.2	17.3	54.053	2111.48
	B33	30.4	17.6	55.451	2167.44
3	B34	31.4	17.0	54.288	2130.94
	B35	31.0	17.0	53.523	2109.57
	B36	32.1	17.1	55.143	2183.76

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4. Result and Discussion:

This section presents the results of tests which are conducted to evaluate the impact of mechanical properties on the steel and the effect of the water used in ready-mixed concrete on the corrosion behavior of rebar.

Table 5: Values recorded of yield point, tensile strength and bending tests for the "TS-4 samples of rebar

Smp	Nominal Area mm^2	Yield point YP N/mm^2	Tensile strength TS N/mm^2	Elongation EL %	Ratio TS \YP %	Bend Test
1	314	527	962	14	1.82	OK
2	314	454	767	16	1.68	OK
3	314	470	779	16	1.65	OK

Table 5 shows that mechanical tests for TS-4 the upper value of tensile strength recorded 962 Mp_a, also the upper value of yield strength recorded 527Mpa, and tensile strength divided to yield strength equal 1.82 that these were indicating to high ability to withstanding mechanical deformations, makes it suitable for using in special constructions due to its high carbon and alloy content[10] , that noted by its content in the table 7 . fig5 shows sample 1 exhibited higher tensile strength and yield strength than the others, indicating to higher mechanical properties.

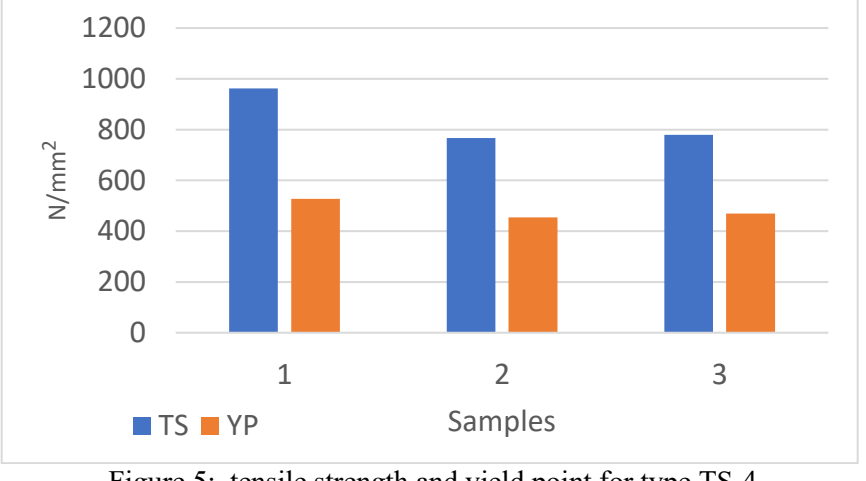

Figure 5: tensile strength and yield point for type TS-4

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Table 6: Values recorded of yield point, tensile strength and bending tests for TS-40 samples of rebar

Smp	Nominal Area mm^2	Yield point YP N/mm^2	Tensile strength TS N/mm^2	Elongation EL %	Ratio TS \YP %	Bend Test
1	314	517	627.1	20	1.21	OK
2	314	516	625.3	21	1.21	OK
3	314	548.5	652.8	22	1.19	OK

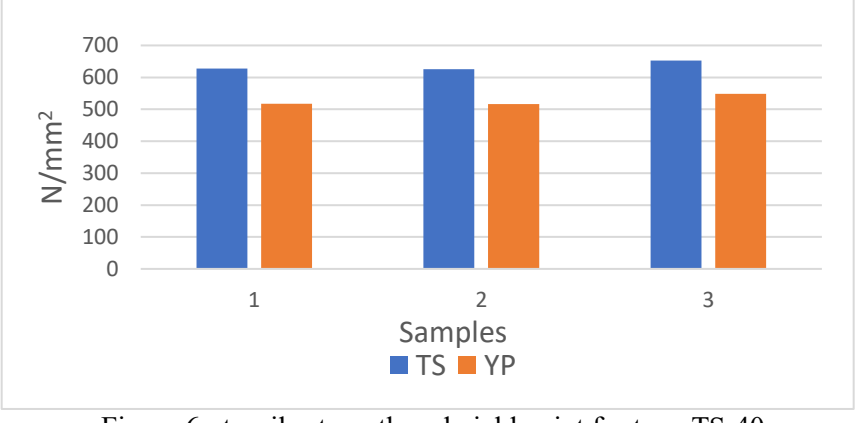

Figure 6: tensile strength and yield point for type TS-40

from table 6 it was observed that TS-40 values were within the permissible range for rebars according to the specifications ASTM A615, which that recorded by upper tensile strength recorded equal 652.8 Mpa and upper yield strength equal 548.5 Mp_a so that, upper ratio of tensile strength divided to yield strength equal 1.21 while fig(6,7) shown the difference and comparison between the two types

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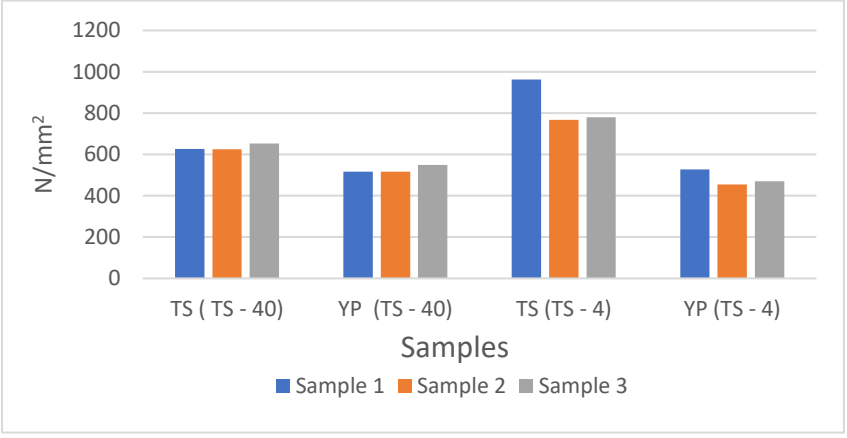

Figure 7: comparison between tensile strenght and yield point testes for both types TS-40 & TS-4

From Table 7 observed the proportions of carbon and elements of alloys was higher in TS-4 than in TS-40 this led to effect on the elongation and resistance to mechanical deformation, which were higher in TS-4 compared to TS-40

Table 7: chemical analysis test for the both types of rebar TS-4 and TS-40

Smp	C	Si	.Mn	P	S	Cr	Mo	Ni
TS_4								
1	0.45	0.24	1.58	0.011	0.013	0.024	0.002	0.008
2	0.39	0.20	1.25	0.015	0.014	0.013	0.003	0.008
3	0.44	0.24	1.35	0.013	0.012	0.027	0.002	0.003
TS_40								
1	0.22	0.20	0.62	0.011	0.028	0.009	0.001	0.010
2	0.21	0.20	0.60	0.011	0.027	0.009	0.001	0.010
3	0.22	0.20	0.61	0.009	0.021	0.009	0.001	0.008

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Smp	Cu	Sn	Al	Co	Nb	Ti	V	Zr
TS_4								
1	0.014	0.002	0.001	0.004	0.002	_	0.006	_
2	0.015	0.001	_	0.003	_	_	0.005	_
3	0.003	_	_	0.002	_	_	0.007	_
TS_40								
1	0.006	0.002	_	0.005	_	_	0.004	_
2	0.007	0.002	0.001	0.005	_	_	0.004	_
3	0.005	0.001	0.001	0.005	_	_	0.004	_

Table 8: values of chemical analyses of water samples before placing samples of rebar

Water samples	chloride Cl mg/l	Temp T^0 C^0	Total Dissolved Solids TDS mg/l	Conductivity CON S/m	potential of Hydrogen PH
C	>82.5	23.1	320	585	8.1
D	40.9	22.8	1173	2112	7.8
E	79.7	23.3	650	1179	8.25

Table 8 shows that quality for water parameters of that three samples types were collecting (C, D, E) they were within the specifications ASTM C1602&bs1008 for water that used in concrete, also observed from the low total Dissolved Solids (TDS) readings that obtained from the chemical analysis test provide evidence through chemistry that any sulfate or phosphate ions present exist in insignificant quantities within safe levels set out internationally like in ASTM C1602 also, that sample of water (D) recorded decrees value of chloride (CL) compared with samples (C&E) so that will be low effect of corrosion on the both types [14], Figures (8–10) illustrate the graphical representation of total dissolved solids (TDS), Potential of Hydrogen (pH) and electrical conductivity (con), facilitating the interpretation and comparison of the results.

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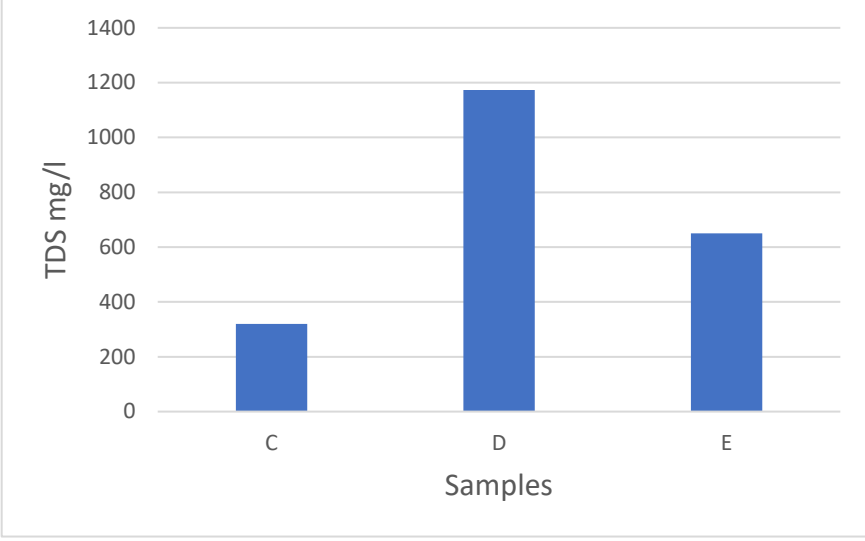

Figure 8: Total dissolved solids T, D, S for three types of water samples C, D, E that were collected from ready-mixed concrete plant

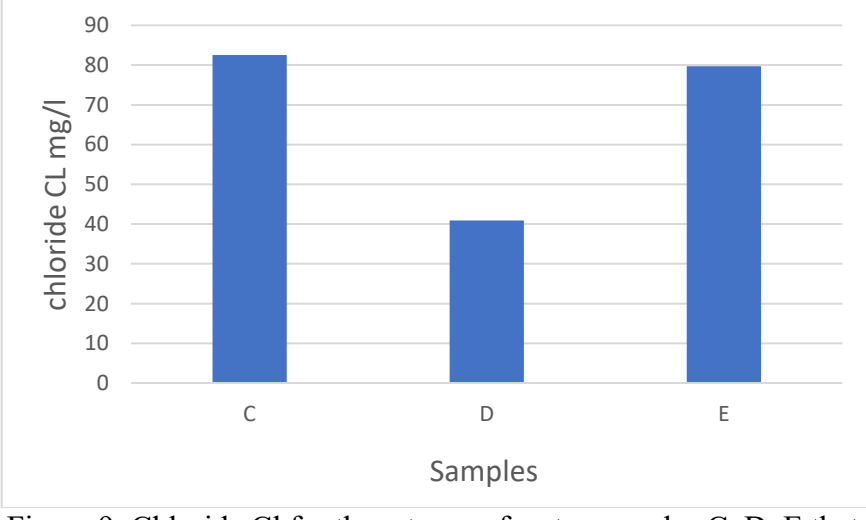

Figure 9: Chloride Cl for three types of water samples C, D, E that were collected from different concrete plant

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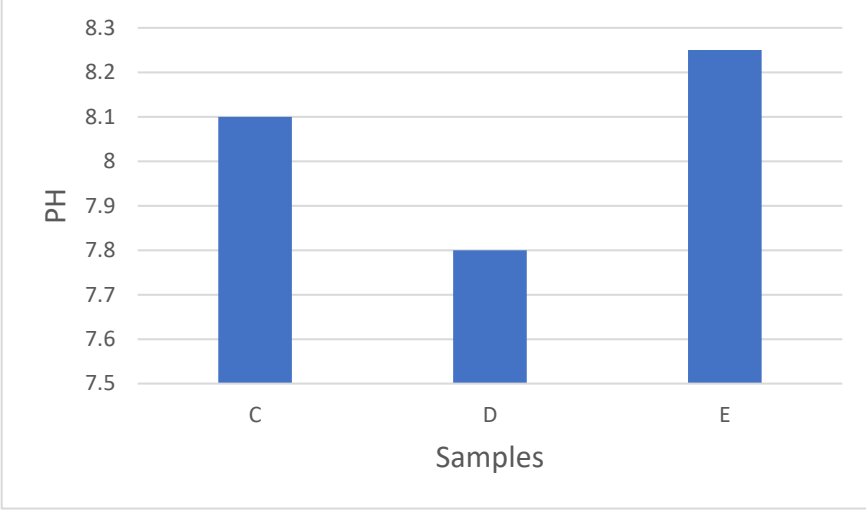

Figure 10: Potential of Hydrogen for three types of water samples C, D, E that were collected from different ready-mixed concrete plant

The corrosion behavior of rebar samples was evaluated by conducting corrosion tests; the following tables and figures present the obtained results and their graphical

Table 9: Average of reading corrosion weight loss for TS-4&TS-40 samples that measured each two weeks for all period six weeks

Water sample	Sum reading corrosion TS-4 gm	average corrosion gm	Sum reading corrosion TS-40 gm	average corrosion gm
C	0.363	0.121	0.322	0.107
D	0.263	0.087	0.288	0.096
E	0.325	0.108	0.381	0.127

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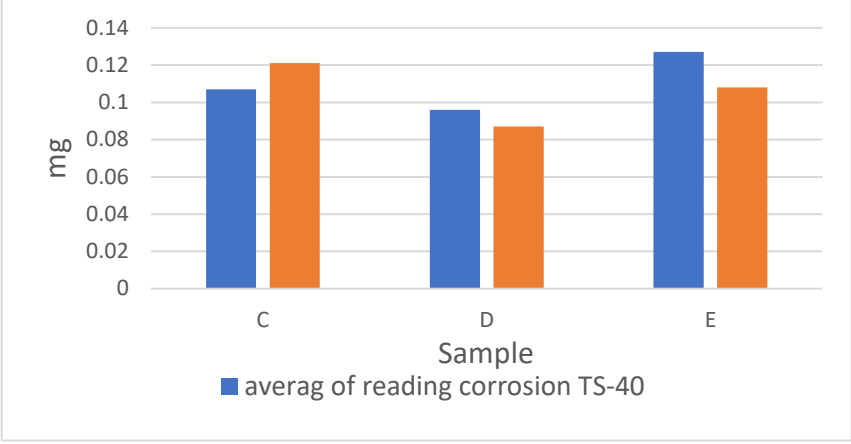

Figure 11: Reading the average weight loss of corrosion that were using three types of different water measured after two weeks that total period six weeks

Table 10: Average of reading corrosion weight loss for TS-4 & TS-40 of samples that measured after six weeks period

Water sample	Sum reading corrosion TS-4 gm	average corrosion gm	Sum reading corrosion TS-40 gm	average corrosion gm
C	0.409	0.136	0.355	0.111
D	0.292	0.097	0.293	0.097
E	0.336	0.112	0.406	0.135

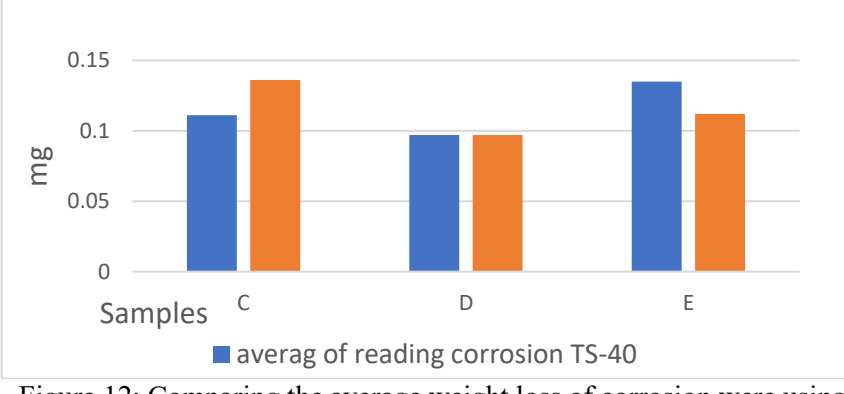

Figure 12: Comparing the average weight loss of corrosion were using three types of samples water that measured after six weeks

From tables 9&10 it observed that the corrosion rates were had close values for both types TS-4 and TS-40 in that of water samples due to the chlorides less than the critical point that around less than 100 mg/L, led the effect was decreasing due to chloride percentage[14][15] which was reflected in the lower corrosion rate for both types of rebar that immersion in sample of water D that equal 0.087 mg of weight loss after average each two weeks for period six weeks , equal 0.097 mg for six weeks consecutively. The variation of carbon percentage from 0.22 % to 0.45%, leads to increased corrosion ratio, this was due to the higher amount of the softer and low resistant ferrite phase, leads to Galvanic cells [15][16]. A higher TDS value leads to increased conductivity, this leads to an aggressive medium, and increased the ratio of corrosion for low carbon type TS-40 that immersion in sample of water (E), due to the flow of the corrosion current. Furthermore, the high ionic strength increased the activity chloride ions to destroying the protective layer[10][17].

5. Conclusions:

TS-4 indicates a high ability for withstanding mechanical deformations, making it suitable for use in special constructions due to its high carbon and alloy content that compared with TS-40, and this were affected on elongation and resistance to mechanical deformation, which were higher in TS-4 compared to TS-40.

The qualities of water parameters samples for three types (C, D, E) they were within the specifications of water that used in concrete mixture.

The corrosion ratio was close for both types TS-4 &TS-40 when immersion in that three types of water samples (C, D, E) because the chloride values were less than the critical point so that the effected of corrosion was close.

The increases of carbon percent content for that TS-4 to TS-40, leads to increased corrosion rates, also increases TDS leads to increases the conductivity, so that increases the corrosion ratio of low carbon TS-40.

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