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Studying the Electrochemical Behavior and Corrosive Properties of Bodroon Meat Can

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Keywords:
Bodroon meat cans; Mild steel; Inner coating layer; Electrochemical behavior; Corrosion rate.

Highlights:

- *The inner coating layer corrosion rate in meat cans depended on the tin content percentage.*
- *The corrosion resistance increased with Sn% in the inner coating layer of cans.*
- *Adding 0.50% tin to the inner coating layer showed the lowest corrosion rate.*

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Abstract: Bodroon meat cans are made from a can container of mild steel and coated with an inner layer that touches the food material. The inner coated layer contains a food-grade polymer containing 0.03% tin. This paper aims to study the effect of the tin percentage on the electrochemical behavior and corrosion resistance in serum from Bodroon canned meat. The Tafel extrapolation method was used to determine the electrochemical behavior and corrosion rate. Meat serum was prepared from 10 grams of canned meat dissolved in 90 milliliters of distilled water. Different percentages of tin were chosen, i.e., 0.03, 0.3, 0.35, 0.40, 0.45, and 0.50 by weight %. The tin was added in a nano scale to the polymer to form the inner coating layer. The results proved that as the percentage of tin increased in the polymer, its corrosion resistance increased. The corrosion rate was 0.00377 mpy when adding 0.50% Sn, while it was 0.0818 mpy when adding 0.03% tin. Adding 0.03% Sn is currently used for coating the inner layer of the Bodroon meat cans. The distribution and homogeneity of the interior coat and the effects of corrosion on the interior coated layer were also studied using a scanning electron microscope SEM. The novelty of the research does not lie in using tin in the inner coating layer of 0.03% Sn, as was dealt with in previous works and based on which the current meat cans were made. The results of the present work proved that using 0.03% tin in the polymer coating layer was insufficient to prevent corrosion. The best results showed that adding 0.50% tin had the lowest corrosion rate, which is an essential point because if the corrosion leads decomposition of the coating material to spread the metal ions to the food substance, causing its contamination that harms human health.

دراسة السلوك الكهروكيمياوي وخواص التاكل لعلب لحم بودرون

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الخلاصة

تصنع حاوية معلبات اللحم بودرون من الفولاذ منخفض الكربون المطلي من الداخل بطبقة من البوليمر الغذائي الحاوي على ٠,٠٣٪ قصدير وان طبقة الطلاء الداخلية تلامس المادة الغذائية. يهدف البحث الحالي الى دراسة تأثير نسب القصدير الموجودة في البوليمر الغذائي على السلوك الكهروكيميائي ومقاومة التاكل في مصل اللحم بودرون. تم استخدام طريقة استكمال منحني تافل في هذا العمل. تم تحضير مصل اللحم باذابة ١٠ غم من اللحم المعلب مذاب في ٩٠ مل ماء مقطر. وقد تم اختيار نسب من القصدير ٠,٠٣ ,٠,٣٠ , ٠,٣٥ , ٠,٤٠ , ٠,٤٥ , ٠,٥٠ % اضيفت على شكل جزيئات نانوية الى البوليمر لتشكيل طبقة الطلاء الداخلية. اثبتت النتائج انه كلما زادت نسبة القصدير في البوليمر زادت مقاومة التاكل له. وكانت قيمة معدل االتآكل هي 0.00377 mpy عندما كانت نسبة القصدير تساوي ٠,٥٠٪، بينما كانت قيمة معدل االتآكل mpy ٠,٠٨١٨ عندما كانت نسبة القصدير تساوي ٠,٠٣٪ وهي النسبة المستخدمة حاليًا لتغليف العلب الداخلية لمعلبات لحوم بودرون. كما تم دراسة توزيع وتجانس انتشار طبقة القصدير في طبقة الطلاء ودراسة طبيعة سطح الطبقة بعد حصول االتآكل باستخدام المجهر الالكتروني الماسح SEM. ان اصالة البحث الحالي لا تكمن في استخدام القصدير في الطبقة الداخلية والتي تستخدم ٠,٠٣٪ من القصدير كما تناولتها الاعمال السابقة وصنعت على ضوئها علب اللحوم الحالية. بينما اثبتت نتائج البحث الحالي ان استخدام ٠,٠٣٪ من القصدير في طبقة الطلاء الداخلية لمعلبات بودرون لا تكون كافيه للحماية من التآكل، حيث كانت نسبة ٠,٥٠٪ أفضل لحماية الطبقة من التاكل. وهي تُعد نقطة جوهرية يجب اخذها بنظر الاعتبار لأن حصول التآكل بمعدلات قليلة سوف يؤدي الى تحلل طبقة الطلاء وانتشار التاكل إلى سطح المعدن الاساس، إن انتشار ايونات المعدن في المادة الغذائية له تأثير سلبي على صحة الانسان.

الكلمات الدالة: معلبات اللحوم بودرون، الفولاذ منخفض الكربون، طبقة الطلاء الداخلية، السلوك الكهروكيميائي، معدل التاكل.

1.INTRODUCTION

Food products sealed in a sealed container and processed at about 100 °C are called canned food. The Potted meat food product contains high amounts of fat, meat broth, vinegar, garlic powder, onion powder, salt, flavoring, spices, sugar, flavorings, sodium erythorbate, sodium nitrite, and preservatives, which may make it corrosive media [1]. With increasing demand for canned meat and its quality, there are increasing requirements for improving methods for controlling total production and evaluating the quality of its basic containers to preserve its morphological characteristics, biological properties, and nutritional value. Some histological studies of canned meat revealed the presence of foreign canned meats, which showed in the microscopic structure the presence of fibrous connective tissue, impurities of periosteum fragments, soy fragments, and starch fragments, which are unmentioned in the standard, which requires much research and studies given the importance of these materials and their connections to the health of those who consume them [2]. Metals like tinplate and aluminum are frequently used to create containers and locks for food and beverages, and tin canning is still a major industry today [3]. Metal cans are internally coated to prevent aggressive contents from interacting with the can, which must be avoided to prevent corrosion and food poisoning [4]. When food is packaged in tin-plated iron cans, the tin level is a good indication of how long the food will keep [5]. Trace elements enter the human body mainly through food and other sources, including water and air. There is strong proof that various trace elements the amounts, and chemical forms correlate with their health effect, such as essentiality or toxicity [6]. Food contamination with tin can occur naturally due to environmental pollution, packing, or use of pesticides, pH level, the presence of oxidizing substances (nitrate, iron, and copper), the presence of air (oxygen) in the headspace, time, and the temperature of storage all affect the speed at which tinplate dissolves. Cans are typically coated to prevent corrosion and tin dissolution, greatly decreasing tin diffusion into food products [7]. The International Health Organization indicated that eating food contaminated with iron, its oxides, and rust harms human health that sometimes leads to death [8]. Sn is coated on the steel by tinning. In this process, the can is coated by immersion in molten tin hot dipping or electrolysis. Tin protects steel by "sealing" the surface from the atmosphere so that the tin layer is too thick and unattractive [9]. The meat cans were originally made of steel sheets coated with a tin layer consisting of the base (Sn) and polymer [10, 11]. Sn is less active (nobler) than steel (Fe); therefore, it is used to prevent steel corrosion [12, 13]. Additive chemicals, such as inhibitors, acid neutralizers, or softeners, can enter into side reactions that result in a corrosive solution that corrodes tin. In this case, tin corrodes according to the following equations [14, 15]:

$$Sn + 2OH^- \rightarrow Sn(OH)_2 + 2e^- \quad (1)$$

$$Sn(OH)_2 \rightarrow SnO + H_2O \quad (2)$$

$$SnO + H_2O + 2OH^- \rightarrow Sn(OH)_4 + 2e^- \quad (3)$$

$$Sn(OH)_4 \rightarrow SnO_2 + 2H_2O \quad (4)$$

The reduction reactions depend on the pH of the environment, as shown in the following equations: [16, 17].

$$2H^+ + 2e^- \rightarrow H_2 \quad (5)$$

(In an acidic solution)

However, if oxygen is present, two other reactions may occur:

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \quad (6)$$

(Acid solutions)

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad (7)$$

(Neutral and alkaline solutions)

The Sn corrosion resistance in distilled water is more than in seawater and tap water because the first one has less amount of salt; however, it is attacked by mineral and organic acids. Strong acids, alkalis, and acid salts can be found in canned meat [18]. Corrosion of steel occurs in several stages. The initial attack occurs at anodic areas on the surface, where ferrous ions enter the environment. Electrons are released from the anode and move through the structure to the adjacent cathodic sites. These react with the ferrous ions from the anode to produce ferrous hydroxide, which is further oxidized in air to produce hydrated ferric oxide. The sum of these reactions is described by the following equation, appearing as red rust [19].

$$4Fe + 3O_2 + 2H_2O \rightarrow 2Fe_2O_3.H_2O \quad (8)$$

{Steel + oxygen + water → Red rust} (9)

The corrosion danger in canned meats to human health lies in several aspects. Either metal ions such as tin ions or steel ions enter to spread and pollute foodstuffs, or the corrosion products enter foodstuffs. Tin oxides SnO or SnO_2 dissolve in acids and alkalis, spreading and polluting the foodstuff. The hydroxides $Sn(OH)_2$ and $Sn(OH)_4$ precipitate as a white amorphous precipitate. Its hydroxide is poorly soluble in water, and both have amphoteric properties. $Sn(OH)_2$ and $Sn(OH)_4$ dissolve in acidic solutions, and salts containing M^{+2} and M^{+4} ions are formed. These hydroxides react with basic solutions, forming salts compatible with the two acids H_2SnO_2 and H_4SnO_4. If tin ions, oxides, or hydroxides enter the human body, it may cause infection with what is known as tin plague, as explained in previous studies [8, 20]. Previous studies and research proved the possibility of depositing a beta-tin phase. Tin has two main allotropes. The stable allotrope is β-tin, a silvery-white, malleable metal. However, at low temperatures, it transforms into the less dense grey α-tin, which has a diamond cubic structure. Metallic tin is not easily oxidized in air [21]. The present research aims to study the effect of the percentage of tin nanoparticles in the polymer (polycarbonate) on the electrochemical behavior and corrosion resistance of serum from Bodroon canned meat.

2.EXPERIMENTAL WORK

2.1.Apparatus and Procedures

2.1.1.Optical Emission Spectrometry

The raw materials used in this work were Bodroon meat cans from the local market. The chemical analysis of these cans showed that the cans consisted of mild steel containers coated with food polymer, and 0.03% Sn was in the cans' inner coat layer. This analysis was performed using an Optical Emission Spectrometry robust mobile model, German manufacturing, by Al-Nabaa Co. Engineering Service Ltd. located in Baghdad.

2.1.2.pH Meter

The canned meat serum pH was 6.46. This pH was constant in all the samples. The pH test was done using a WTW device in the Mayoralty of Baghdad/Baghdad Water Office.

2.1.3.Corrosion Rate Measurement

The corrosion rate was measured by the Tafel extrapolation method. This method depends on plotting the relationship between the applied potential (mV) and logarithmic current density (A/cm²). The general equation applied for determining corrosion rate by current density in meat serum solution on the samples during the electrochemical reactions is:

$$\text{Corrosion rate (mpy)} = 0.13 \times I_{corr.} * eq./\rho \quad (10)$$

where:

I_{corr}: Corrosion current density (μA/cm²).

eq: Equivalent weight (g/equivalent).

ρ: Density (g/cm³).

The electrochemical behavior and corrosion resistance were examined by an electrochemical cell, 250 ml in size, containing three electrodes: the test spaceman, the standard electrode, i.e., the hydrogen electrode SHE, and the reference electrode, the calomel electrode.

2.1.4.Fourier Transform Infrared Spectroscopy (FTIR)

The inner coated layer of the base can was analyzed using Fourier Transform Infrared Spectroscopy (FTIR) type (IRAffinity-1-SHIMADZU). The analysis results are presented in the results section.

2.1.5.Atomic Absorption Spectroscopy (AAS)

Atomic Absorption Spectroscopy (AAS) is a method for determining the amounts of metallic elements in various materials. It uses electromagnetic wavelengths from a light source as an analytical method. Different substances absorb these waves in different ways. The tin analysis is equally simple to perform using high-brightness lamps and a hydrogen-air flame as any other atomic absorption analysis. Type (AA-7800-SHIMADZU) was used to determine the tin metal content in the inner coated layer.

2.1.6.Scanning Electron Microscopy (SEM)

SEM (type (JSM-IT710HR)) was used in this research to examine the corrode surface morphology. SEM was used with an operating voltage of 3.5-10.00 kV at a resolution of 400 nm. An electron microscope type images the surface using high energies of electrons beam.

2.2.Experimental Work Procedure

The corrosion rates in the meat serum were measured in two stages. In the first stage, the corrosion rates were separately measured for the base metal and inner coated layer. The base metal was made of low-carbon mild steel. The corrosion rate of the inner coating layer, which is in contact with the foodstuffs, was measured. The inner layer consisted of a polymer containing 0.03% tin. The second stage included measuring the corrosion rates of new coating layer material consisting of the same polymer as the base coating material, while the tin ratio of tin was changing to (0.03, 0.3, 0.35, 0.4, 0.45, and 0.5) wt. % separately to extract the best percentage of tin in the coating layer material with the lowest corrosion rate would be. Figure 1 shows the flow chart of the work procedure.

2.3.Materials

2.3.1.Metal of Bodroon meat can

The Bodroon meat cans used in this research were made of low-carbon steel coated with a protective layer. The thickness of the inner coating layer was 36.95 µm. The thickness of the metal without a coat was about 181µm, while the thickness of the base metal was also determined from the optical microscopic image. The measurements in the two methods corresponded.

2.3.2.Preparation of Meat Serum

The meat serum was prepared from a protein medium of cooked cut meat by dissolving 10 grams of meat in 90 ml of distilled water. The obtained solution was mixed well and then filtered. The serum solution was kept at a low temperature [22]. The solution had a pH of 6.46.

2.3.3.Chemical Composition of the Metal Can

The chemical composition of the Bodroon meat can be analyzed in the (Al-Nabaa Co. Engineering Service Ltd./Baghdad. Using Spectrometer type (PMI Master pro) optical emission spectrometer (OES) (S.N52Q0089). The chemical compositions of the metal are shown in Table 1.

2.3.4.Tin Nanoparticles (Sn_{-Np}), Polycarbonate (PC), and Solvent Chloroform or Trichloromethane (TCM)

Different weights were taken from the tin powder container, i.e., 3 gm of the base metal polymer and 3 gm of polycarbonate granules, and placed in a glass beaker. Chloroform was used as a solvent for the polymer, and different percentages of tin were added to the samples, except for the base metal sample, which contained a small tin percentage. The baker was placed on the heater with shaking, and then the samples were cast and dried, as shown in Table 2.

2.3.5.Coating Remove from the Plate Can

To remove the coated layer from the can, a metal can was cut into pieces of different dimensions to collect the inner polymer of the base metal. 50 g of NaOH was placed in 500 ml of distilled water [23] with mixing and heating on a hotplate. The can metal samples were immersed in the Sodium Hydroxide solution. The polymer layer was easily removed from the inner surface of the metal and appeared in the form of strips.

2.3.6.Preparation of Polycarbonate with Tin Samples

Different tin powder weights, i.e., 3 gm of the base metal polymer and 3 gm of polycarbonate granules, were placed in a glass beaker. Chloroform was used as a solvent for the polymer. The polymer was dissolved in 5 ml of chloroform with continuous heating and stirring. Table 3 shows the tin nanoparticles concentration with polycarbonate. Then, hot dip coating was achieved at 100 °C to deposit six layers of tin-polycarbonate and compare it with the base coating layer. It was poured on a glass plate and left for 24 hours to dry (Figs. 2 and 3).

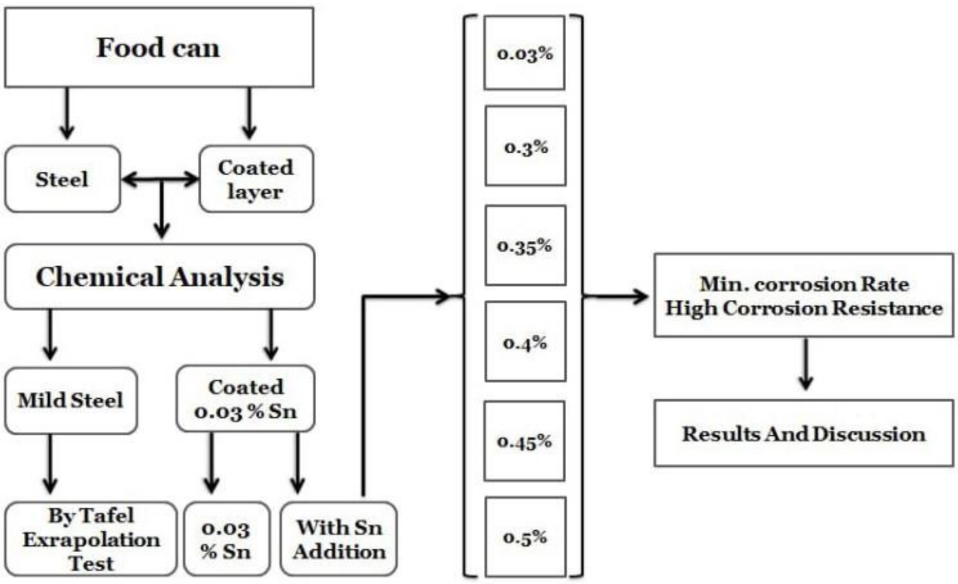


Fig. 1 Flow Chart of the Work Procedure.

Table 1 Chemical Analysis of the Metal of Meat Can.

Chemical Composition	Fe	C	Mn	Cr	Al	Co	Cu	Others
Average Values wt.%	99.50	0.053	0.205	0.042	0.034	0.036	0.016	0.114

Table 2 Chemical Composition Details.

Materials	Chemical Formula	Supplier	Chemical and Physical properties			
			Particle Diameter nm	Purity %	Density g/cm3	Molar mass g/mol
Polycarbonate (PC)	$C_{15}H_{16}O_2$	USA	$3*10^6$	100	1.22	272.29
Chloroform	$CHCl_3$	USA	12	99.8	1.49	119.38
Tin	Sn	England	5	99.98	7.30	118.71

Table 3 The Concentration of Tin Nanoparticles with Polycarbonate.

Polymer	Polycarbonate (PC)	PC	PC	PC	PC	PC
(Sn)wt.%	0.03	0.3	0.35	0.4	0.45	0.5

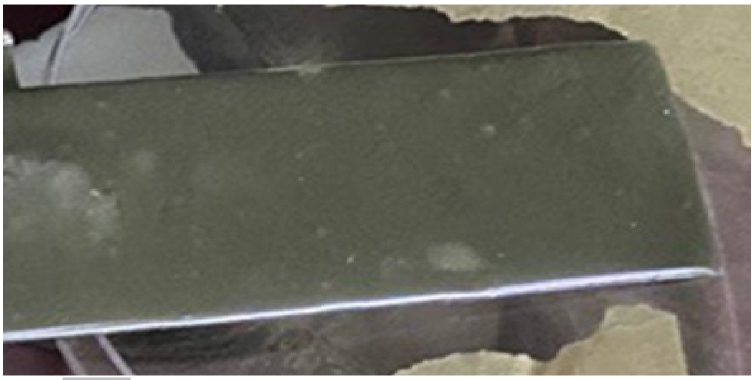


Fig.2 Polycarbonate with Tin Cast on the Glass Plate.

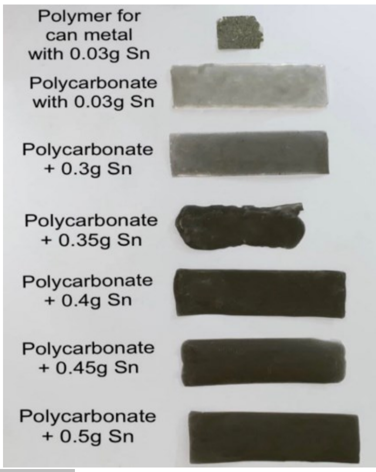


Fig. 3 Different Tin Percentages Added to the Polymer.

4.RESULTS AND DISCUSSION

This section displays the results and discusses the electrochemical behavior and measurements of the meat cans' corrosion rate. The samples were examined using FTIR, Atomic Absorption Spectroscopy, and Scanning Electron Microscope.

4.1.Fourier Transform Infrared Spectroscopy (FTIR)

The infrared beam impacted the bonds, increasing the vibrations amplitude. Only particular frequencies of the infrared beam will be absorbed because quantized vibrations occur at particular vibrational energy levels in a molecule. The test was conducted in the Analysis Center Laboratory/ Baghdad, Japanese device type (IRAffinity-1-SHMADZO), with wave numbers 4000-500 cm^{-1}, and was used to analyze the samples' molecular vibrations. The absorption peaks at 3423.39 cm^{-1} were associated with water (O–H) stretching vibration mode and water bending. The absorption band at around 3000 to 2800 $cm^{-1}$is (C-H) stretching vibration band. The polymer coat was pulled from the inside of the metal can and examined in FTIR.

The result of the metal can polymer that contained 0.03% Sn is shown in Figure 4. Only this sample contained the effective group of O-H. By comparing the metal-polymer analysis result with the polycarbonate standard at peak 1767 cm^{-1}, it was found that a polycarbonate type. The carbonyl peak produced by oxygen atoms double bonding to the carbon atom (C=O) was attributed to the primary peaks in the FT-IR analysis of pure polycarbonate at 1767 cm^{-1}. All samples consisting of (C=O) stretching vibration approximated the same peak of polycarbonate standard. The polycarbonate compound included phenol in its preparation, as shown by its effect on the samples. The frequency response of two phenol rings peaked from 1506-1450 cm^{-1} due to the stretching of the phenol ring. The results shown in Table 4 included the fractional grope of the samples. The absorption peaks at 3423.39 cm^{-1} were associated with water (O–H) stretching vibration mode and water bending. The peak 2949.13 cm^{-1} represents the C-H Stretching. The peak of 1720.20 cm^{-1} represented C=O stretching after the corrosion test. The peak of O-H stretching was 3657.04 cm^{-1}.

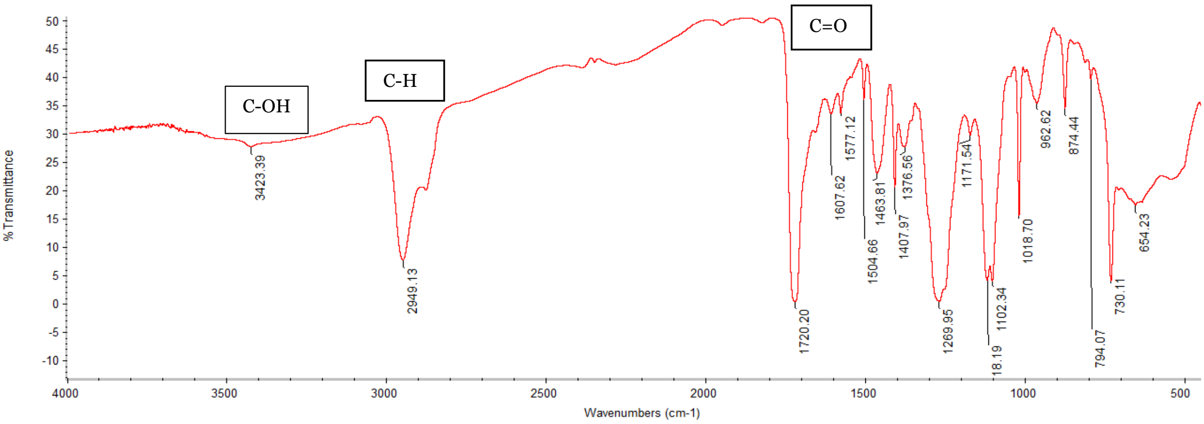


Fig. 4 FTIR Analysis of Metal Can Polymer.

Table 4 Fractional Group in the Polycarbonate Samples with Different Concentrations of Tin.

Bond type	Functional group	Wavenumber (cm⁻¹)						
		Metal polymer	PC+0.03% Sn	PC +0.3 % Sn	PC+0.35% Sn	PC+0.4 % Sn	PC+0.45% Sn	PC + 0.5 %Sn
O-H	Hydroxyl	3423.39	-	-	-	-	-	-
C-H	Stretching	2949.13	3059.11	2951.09	2958.80	3008.95	2962.66	2920.23
C=O	Stretching	1720.20	1766.80	1766.80	1766.80	1766.80	1766.80	1766.80
phenol ring -OH	Aromatic organic compound	1504.66	1504.48	1500.62	1500.62	1500.62	1500.62	1500.62

4.2.Atomic Absorption Spectroscopy (AAS)

Atomic absorption spectroscopy of tin analysis is simply performed using high-brightness lamps and a hydrogen-air flame as any other atomic absorption analysis. The metal samples were dissolved and placed in a nitric acid solution. The tin was separated from the solution in the form of a liquid. The tin was tested in the atomic absorption device. The test showed that the sample contained 0.03 wt. % of Tin.

4.3.Corrosion Rate Calculations

The cans suffer from two types of corrosion: the container, made of low carbon steel, corrosion, and the inner coating layer corrosion. Both types of corrosion rates were measured. Table 5 shows the electrochemical parameters and corrosion rate calculated from the Tafel Extrapolation curves. Table 5 shows that the corrosion rate of the inner coated layer was less than the mild steel container without coating. These results are contributed to the electromotive force EMF series. The corrosion potential for the polymer containing Sn was higher than for mild steel alone [24], meaning that using polymer containing Sn provides good protection for mild steel. The Sn acts as a cathode compared to mild steel, which acts as the anode. Placing meat in a container is like an accident waiting for toxic ions to spread into it; however, in light of the good container and preservation manufactured in the appropriate conditions, it is possible to avoid corrosion and prevent the metal ions from being released [25]. It may be taken carefully to keep the inner coated layer healthy without scratching, rupture, or cracking. The rupture or scratching with steel. In this condition, the mild steel accelerated corrosion. As Sn content increased in the coating layer, the corrosion rate decreased, as shown in Table 5. The corrosion rate was 0.03% > 0.3% > 0.35% > 0.4% > 0.45% > 0.5%. The samples' electrochemical analysis collect curves of the mild steel, inner coating layer, 0.45% Sn, and 0.5% Sn are shown in Fig. 5. The Tafel curve of the sample with 0.5% Sn had lower current density than the sample with 0.45 Sn, i.e., increasing the tin concentration decreased the corrosion current density and rate. The inner protective layer properties determine the safety of steel from corrosion. The polymer-containing tin layer prevents the corrosive solution from attacking the steel. Since tin has a greater corrosion potential than mild steel, the life of tinned cans is long. It can be concluded from Table 6 that if the tin percentage increases, the corrosion resistance increases, and the corrosion rate decreases. Forming the inner layer of the Bodroon meat can, which currently contains 0.03% Sn in many canned foods commonly used in local markets, tends to have a corrosion rate of 0.0818 mpy. The effect of tin levels was studied in previous research with lower values than in the Bodroon canned food used. Previous works relied on adding small amounts of tin, and the highest percentage of tin added was 0.02% [26, 27]. Figure 7 shows the relationship between potential (E) and the corrosion current density (I) for the sample selected from the other samples containing 0.5% tin. In the present work, the percentage of tin was increased to five values higher than the tin found in Bodroon canned meat, i.e., 0.3, 0.35, 0.40, 0.45, and 0.50%. Using 0.03% Sn in the coating layer is insufficient to prevent corrosion, and decomposition of the inner coat layer may occur, exposing the base metal to corrosion and contaminating foodstuffs with metal ions that greatly harm human health. The results proved that the tin percentage of 0.5% gave the best results and the lowest corrosion rate, i.e., 3.77×10^{-3} mpy.

Table 5 Electrochemical Parameters and Corrosion Rate Calculation for All Samples.

Samples \ Parameters	ba $\frac{mV}{decade}$	bc $\frac{mV}{decade}$	I_o µA/cm²	E_o V	Icorr µA/cm²	Ecorr. V	Corrosion Rate (mpy)	Resistance R mV.cm²/A
Can metal without coating	20	28	0.71×10^{-2}	-0.59	0.082	-0.58	0.0376	6.18×10^{7}
Inner coating layer+ 0.03 %Sn Standard	16	18	1.6×10^{-2}	-0.26	0.0387	-0.26	0.0818	4.72×10^{7}
Polymer with 0.03 % Sn manufacturing	15	12	9×10^{-2}	0.03	0.1240	-0.035	0.2622	1.16×10^{7}
Polymer with 0.30 % Sn manufacturing	13	18	3.8×10^{-2}	0.035	0.1234	0.0346	0.2608	1.49×10^{7}
Polymer with 0.35 % Sn manufacturing	12	18	8.1×10^{-2}	0.063	0.1229	0.127	0.2600	1.25×10^{7}
Polymer with 0.40 % Sn manufacturing	13	15	7.9×10^{-2}	0.03	0.1042	0.042	0.2203	1.44×10^{7}
Polymer with 0.45 % Sn manufacturing	10	18	0.357×10^{-2}	-0.28	$7.9*10^{-3}$	-0.28	0.0168	17.45×10^{7}
Polymer with 0.5 % Sn manufacturing	28	28	0.16×10^{-2}	-0.41	$1.78*10^{-3}$	-0.42	0.00377	168.9×10^{7}

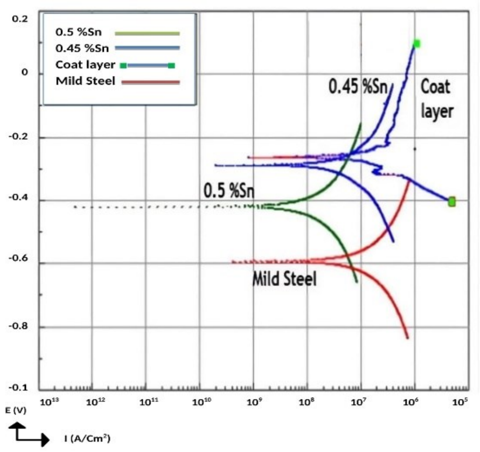


Fig. 5 Tafel Extrapolation Curves Collected for Mild Steel, Inner Coating Layer, 0.45% Sn, and 0.5% Sn.

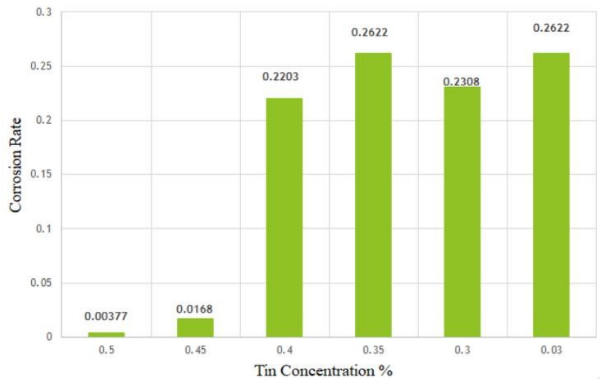


Fig. 6 Relation between the Corrosion Rate and Different Tin Concentrations.

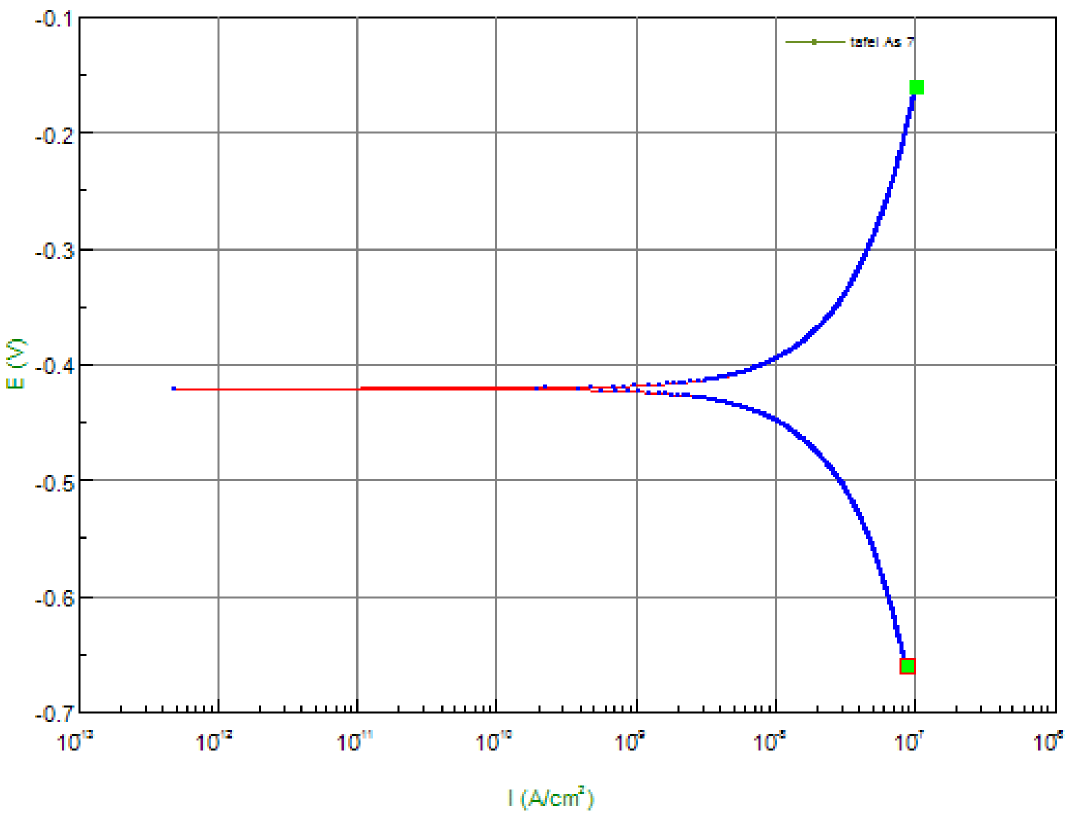
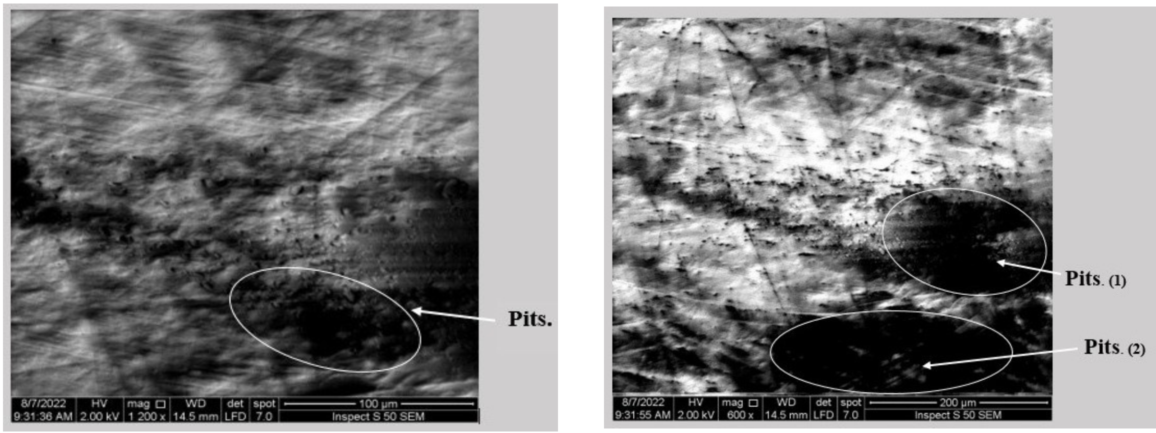


Fig. 7 The Tafel Extrapolation Curves of the Polycarbonate with 0.5% Sn in the Meat Serum Solution.

4.4.Morphology of Corrosion

Experiments revealed that pure tin undergoes two types of localized corrosion processes (Figures 8 A and B), formatting semispherical pits (1) and crystallographic pitting pits (2). Discharges of the first type are characterized by being semispherical and do not appear to have crystallization features. While in the second type of pits, there are manifestations of crystallization, characterized by the solid particles in the pits, as shown in Figure 8. These small solid bodies scattered inside the pits cavities could be a function of a phase transformation of tin. Tin has two main allotropes at room temperature, as shown in Fig. 9. Semispherical pitting occurred on the surface of this material under a simple exposure in a corrosive solution, whereas for formatting the crystallographic pits. These results overview some typical corrosion pitting shapes, including hemispherical pitting and crystallographic pits. At first sight, there is no obvious relation between the composition and the appearance of the alloy surface. However, examining the cross sections with SEM showed that the corrosion of the minimum Sn-containing alloys mainly consisted of a single well-adhering corrosion layer; for some samples, evidence of a second loosely adherent layer. For the samples containing high Sn, the corrosion became more crystallographic pits nature. In many cases, corrosion cracks were observed, showing that the corrosion seemed less adherent to the surface. According to the SEM-EDX analyses, the corrosion layer consisted primarily of tin and oxygen, indicating that the layer was composed of tin oxides and tin hydroxides, as mentioned in the literature [28].



(a) (b)

Fig. 8 SEM Surface Morphology of the Polycarbonate in the Meat Serum after Electrochemical Corrosion (A) with 0.45% Sn (B) with 0.5% Sn.

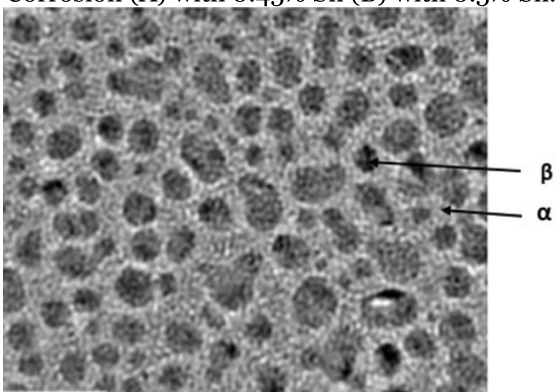


Fig. 9 Two Main Allotropes α/β Phases of Tin.

5. CONCLUSIONS

The present work studied the electrochemical behavior and measurement of the corrosion rate of Bodroon meat cans. The chemical analysis on the can was examined. It was found that the can contained an inner protective layer consisting of a mixture of polycarbonate and a small percentage of tin. The main conclusions of the present work could be summarized as follows:

- The corrosion rate of the inner coated layer in meat serum depended on the percentage of tin content, as follows:
  When
  (a) Sn= 0.03%, the corrosion rate was 0.2622 mpy.
  (b) Sn= 0.30%, the corrosion rate was 0.2608 mpy.
  (c) Sn= 0.35%, the corrosion rate was 0.2600 mpy.

(d) Sn= 0.40%, the corrosion rate was 0.2203 mpy.
(e) Sn= 0.45%, the corrosion rate was 0.0168 mpy.
(f) Sn=0.50%, the corrosion rate was 3.77×10^{-3} mpy.

- As the percentage of tin increased in the inner coating layer of cans, the corrosion resistance also increased. 0.5% Sn had the lowest corrosion rate compared to 0.03, 0.3, 0.35, 0.4, and 0.45% Sn, sufficient to protect from corrosion.
- As Sn% increased in the inner coating layer, the tendency to corrosion decreased.
- Generally, two types of corrosion appeared: corrosion and pitting corrosion.
- Great control in manufacturing cans includes the container, the internal coating layer, and the mechanical stresses. The chemical reactions between the cans' components are essential to preserve them from damage or corrosion. Corrosion in metal containers or their inner coating contaminates the meat with metal ions, harming health. However, if the container is well made and stored in appropriate conditions, corrosion can be avoided, and the material's nutritional value can be preserved and not contaminated.

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NOMENCLATURE

ba	Anodic slope, $mV/decade$
bc	Cathodic slope, $mV/decade$
H	Thickness, mm
Icorr	Corrosion current density, $\mu A/cm^2$
Ecorr	Corrosion potential, V
m	Weight, g
V	Volume, mm^3
OCP	Open Circuit Potential, V
Greek symbols	
α	Alpha-tin
β	Beta-tin
ρ	Density, g/mm^3
Subscripts	
Sn_{Np}	Tin nanoparticles
Pc	Polycarbonate

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