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Preparing Aluminum Alloys to Spot Welding by using immersion coating (Electrical Resistance Welding).

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Abstract

It is the first time that immersion coating phenomenon used for preparing aluminum alloys surface for spot welding. Concentrated aqueous alkaline sodium zincate solution was used to deposit zinc at room temperature and replace an equivalent weight of aluminum from the alloy (G3/5052 or A5/3003) surface which is underneath the electrical insulator aluminum oxide layer which acts as inhibitor for spot welding results in destroying its link to the surface and fall down in the solution as visual white powder, it is similar to shaving process.Zinc coat is then removed by 50% nitric acid. The electrical resistance of the new conducting surface results from this treatment shows a linear relation ship against time up to 30 hours from the time of removal zinc coat according to the equation.

Y= 0.6 X + 3.5

and this indicates that the growth of aluminum oxide is regular during the first 30 hours from the time of exposure aluminum alloy surface to atmosphere. After this period (30 hours) the oxide film start to completion and its electrical resistance tends to be constant. The tensile strength of the welding spot shows a maximum value after 3 hours (19.3 kg/mm^2) from the time of zinc coat removal (from the time of exposure of aluminum alloy to the atmosphere), but a linear relationship is found between tensile strength vs. time obeys the following equation:-Y= - 0.053X + 16.23 Where X between 6-48 hours after zinc coat removal.

الخلاصة

لأول مرة في العالم تستخدم ظاهرة الطلاء بالغمر لتهيئة سطح سبائك الألمنيوم من نوع G3/5052 و A5/3003 للحام النقطي. تم استخدام محلول مائي قاعدي مركز من زنكات الصوديوم لترسيب الخارصين بدرجة حرارة الغرفة ليحل محل وزن مكافئ من الألمنيوم الذي يقع تحت غشاء اوكسيد الألمنيوم (Al_2O_3) العازل للكهربائية والمعرقل لعملية اللحام النقطي. تمت إزالة الخارصين المترسب بواسطة محلول حامض النتريك (50% حجماً). أظهرت المقاومة الكهربائية للسطح الجديد الموصل علاقة خطية مع الزمن لحد 30 ساعة الأولى من زمن إزالة الخارصين عن سطح سبيكة الألمنيوم حيث إن المعادلة التالية تعبر عن هذه العلاقة:-ص = 0.6 س + 3.5

مما يدل على ان نمو اوكسيد الألمنيوم يكون منتظماً بحدود 30 ساعة من تعرض سطح السبيكة للجو بعدها يبدأ اوكسيد الالمنيوم بالاكتمال ومقاومته الكهربائية بالثبوتية.إن الحسابات أظهرت سمك الخارصين المترسب بحدود 21 مايكرون وهذا يعكس بأن مسامية الخارصين بهذا السمك بدأت تتلاشى وطاقة الإحلال غير كافية لاختراق ايونات الألمنيوم لجدار الخارصين المعرقل. أن الفقدان في سطح سبيكة الألمنيوم كان بحدود 6.4 مايكرون من كلا الجانبين حيث يمثل 0.32% من سمك سبيكة الألمنيوم الأصلي (2 ملم) حيث هذا الفقدان لا يؤثر على الصفات الميكانيكية للسبيكة (إبعاد النموذج 130×30×2 ملم).

أظهرت النتائج إن أعلى قيمة لمتانة الشد عند نقطة اللحام هي 19.3كغم/ ملم^2 وذلك بعد ثلاث ساعات من إزالة طبقة الخارصين إلا إن العلاقة الخطية بين متانة الشد والزمن والتي هي:ص = -0.053 س + 16.23

أعطت قيما لـ س بين 6-48 ساعة بعد إزالة طبقة الخارصين.

Introduction

Since aluminum alloys family has an aluminum base, let us review briefly what are know about pure aluminum. The atomic structure is $1S^2$, $2S^2$, $2P^6$,$3S^2$, $3P^1$, or, more simply , a tightly bonded core surrounded by three valance electrons that readily given up. This results in a light, reactive metal with good electrical and thermal conductivity. These properties disappear as soon as the pure aluminum surface exposed to atmosphere due to the oxidation of the surface to aluminum oxide with ΔH°_{forn} = -1675 kJ mol^{-1} [1,2], and high melting point (2050 – 2080°C) and high electrical resistance comparing to the original aluminum metal. This chemical transformation called conversion coating in which the coat is a part of the metal itself [3]. The formed oxide acts as a covered which prevents the diffusion of gases and fumes from and to the metal, thus the welding process will fault or will not performed according to the required specifications. As the thickness of the oxide film increases the electrical resistance of the alloy surface rises until no electrical current will be pass, i.e, the welding process stops [4].

In order to carry out the spot welding process for aluminum alloys in high performance degree, this required the removal of the aluminum oxide film. This oxide is not easy to remove by using acidic or alkaline solutions, thus mechanical process was used manually by using iron brush for the cleaning and removal of the oxide, such process characterize with:-

1.low productivity.

2.difficult to control the removal layer (effected the dimension of the metal).

3.reoxidation of the surface will occur when the alloy left for few hours before welding.

Metal Fabricating plants utilize the resistance welding process to build doors, roots, pilliars, floor pans, deck lids, and most of the other sheet metal subassemblies. A resistance weld is made when current flows for a brief period of time through materials which are held together under pressure. Resistance welding differs from the fusion welding process by its use of mechanical pressure to forge the heated parts together.

A spot weld is made at the weld interface of the parts to be welded when pressure is applied and weld current flows through the electrode tips. A welding transformer transforms the primary high-voltage , low-amperage power supply to usable low-voltage, high amperage secondary weld current. The welding transformer's primary voltage is turned on and off by a welding contactor that is controlled by a timer. The timer determines how long the welding current will flow. An initiation switch starts the operation (Fig.1) [4].

For the above reasons, the requirement for suitable solution for spot welding of aluminum alloys using welding machine becomes necessary. Immersion coating [5,6] is expected to be quite effective to deposit various metals, and it is highly nominated because it has the virtue of simplicity and lower costs compairing with other chemical or mechanical methods. Harraz et al., [7] studied the deposition of metal onto a porous silicon layer by immersion plating from aqueous and nonaqueous solutions. Zuhair studied the immersion coating for different metals (Zn, Cu, Fe, Al, and nickel) in aqueous and nonaqueous solution with different temperature [8].

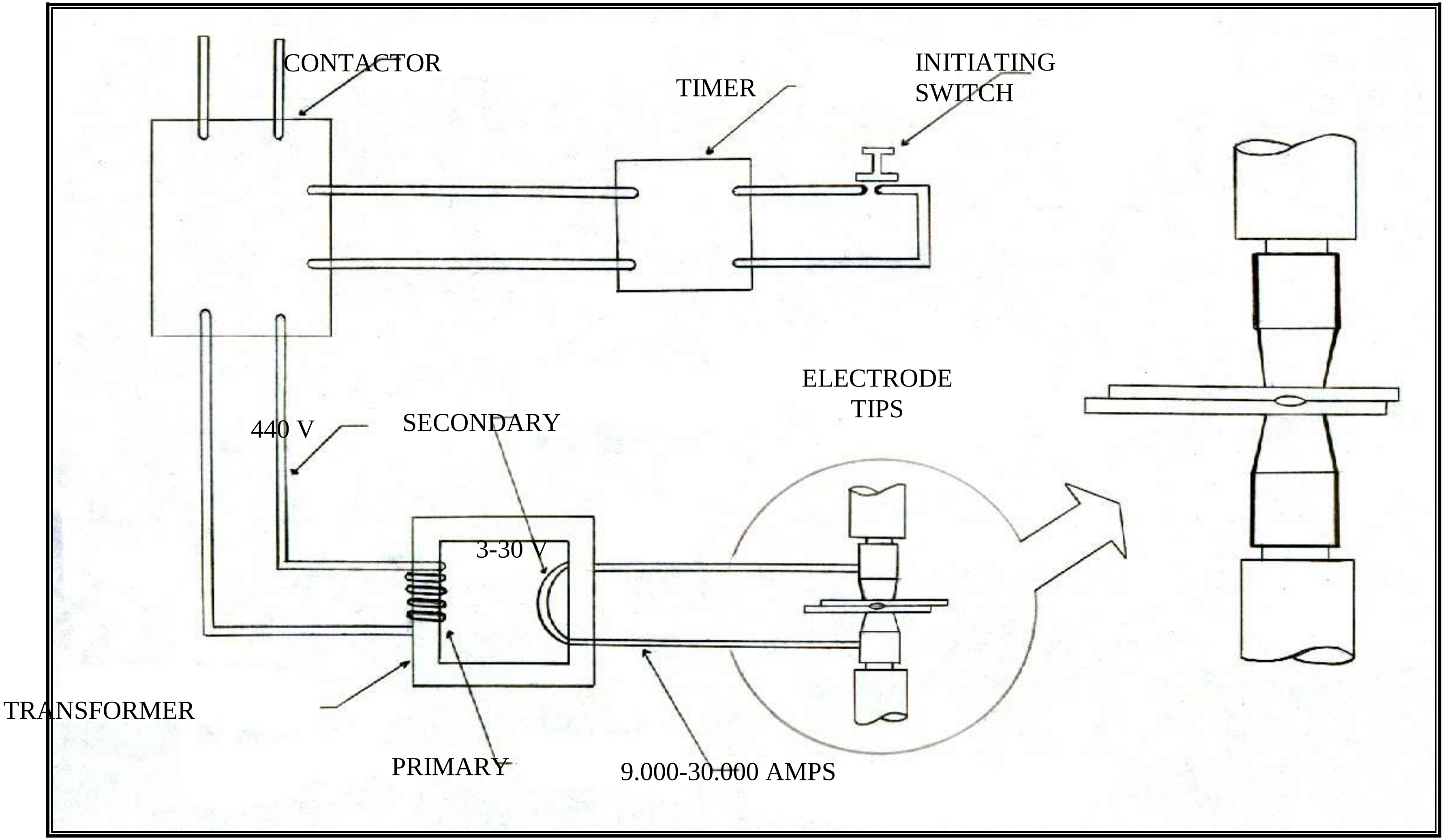

FIG.1 : BASIC WELDING CIRCUIT

Experimental

1. Spot welding machine supplied by Scaky French company. Type P300 Dti 810036, provided with direct digital reading for current, electrical resistance, (microhm), diameter of the welding point, mm, rupture force of welding point , (kg).
2. Stripes of G_3/ 5052 and A_5/ 3003 aluminum alloys with a dimension of 130×30×2mm. Their chemical analyses are carried out in the specialized Institute for Engineering Industries/ Minestry of Industry and Minerals are listed in Table 1.

Table 1: The Chemical composition of aluminum alloys

Alloy	Chemical Composition %							
	Mg	Cr	Mn	Cu	Fe	Si	Zn	Al
G_3/ 5052	2.2-2.8	0.15-0.35	0.1	0.1	0.4	0.25	0.1	Rem.
A_5/3003	-	-	1-1.5	0.05-0.2	0.7	0.6	0.1	Rem.

3. Immersion coating done by the following procedure:
a. Soak clean to removes dirts and oils if present.
b. Cold water rinse.
c. immersion in zincate solution composed of:
- 400 g/L sodium hydroxide.
- 90 g/L Zinc oxide.

Dissolving both of sodium hydroxide and zinc oxide simultaneously at room temperature.
- dipping of the alloy stripe for 2-3 minutes at 20-25°C.

d. Cold water rinse.
e. Nitric acid strip . Immersion in 50% by volume nitric acid for ~2 minutes at 20-25°C. This step is repeated until no change in the weight of the stripe to ensure complete removal of the zinc coat.
f. Rinsing in hot demineralized water for 1 minute.
4. Measurement of rupture force, diameter of the welding spot, and electrical resistance of the alloy stripe.

The electrical resistance of the alloy was measured as a function of time , assuming zero time at the time of removal zinc layer from the surface of the aluminum alloy stripe. Welding and other tests carried on by welding machine mention in item (1).

5. Table 2 shows the results of the tests carried on G_3/ 5052 alloy stripe.

Table 2: Shows the values of the tests carried on the G_3/ 5052 alloy.

Time after removal of zinc layer (hour)	Ruptur's force of welding point (kg)	Diameter of the welding point (mm)	Electrical resistance (microhm)
0	650	7-8	3-4
3	800	7-7.5	5-6
6	800	8	7-8
18	870	8.5	10-17
24	750	8	16-18
48	780	8-9	24

6. Calculation of zinc coat thickness and aluminum thickness dissoluted.
Weight of zinc deposited = 0.0430 g
From the chemical equation:-
$3Na_2ZnO_2 + 2Al + 2H_2O = 2NaAlO_2 + 3Zn + 4NaOH$ ……………(1)
∴ weight of aluminum dissoluted = 0.0118 g
calculation shows that 6.52 microns dissoluted from both faces of aluminum alloy stripe of 2 mm thickness this resembles 0.32% thickness loss.

7. Calculation depends on the true zinc density (bulk density) in which density equals $\rho = \frac{m}{V}$ = 7.14 g/cm^3 ………………………………….(2) not fit for thin film deposited which has different density due to the presence of porosity and vacancies, thus the density of a thin film called apparent density which is equal $\rho_a = \frac{m}{V_a + V_p}$ ………………………………..(3)

Where:

ρ_a = apparent density

V_p = volume of the pores and vacancies in the zinc film.

V_a = apparent volume of the zinc film

ρ_a = for zinc film deposited from alkaline aqueous solution ≈1.5 g/cm^3 [8].

Thus the true volume of deposited zinc will be = 0.0286 cm^3

And the thickness of the zinc film= 0.0021 cm = 21 microns

Results and Discussion

In this research aluminum alloy type G_3/5052, which is used as fuel tank for air force planes in the state company for mechanical industries is treated for successful spot welding. Aluminum alloy type A_5/3003 shows similar behavior to the above alloy for the same purpose. Both alloys their chemical composition are shown in Table 1.

Immersion of aluminum alloy stripe in the sodium zincate bath results in rapidly, dull and loose adhesion zinc film coated on the aluminum alloy which can visually detected. The mechanism of deposition is according to equation (1), which is called immersion or displacement coating. The standard displacement reaction of aluminum by zinc has highly exothermic characters:

$3Zn^{2+} + 2Al = 3Zn + 2Al^{3+}$ $\Delta G^0 = -520$ kJ…………(4)

$\Delta H^0 = -600$ kJ

Results shows that zinc deposited per unit area of the aluminum surface was 0.0032 g/cm^2, literature shows 0.07 g/cm^2 zinc deposited from zinc sulfate + sodium hydroxide solution under the same conditions[8]. This is may be due to the type of chemical form of the deposit metal present in the solution in this research zinc was in the form of zincate anion (ZnO_2^{2-}) while in the latter solution zinc was in the free ion form (Zn^{++}) which is more easily to deposit than in case of zincates anion. This reflects that zinc coating from zincate solution is more economic than that from free zinc ion solution for preparing aluminum alloy for electroplating [7].

Result shows that immersion coating reaction stops when the deposit metal is completely coated the immersed part of the metal or alloy and becomes as electrode (metal immersed in its ions solution, in this work zinc in its zincate ion solution) which is proofed by no change in the weight on the zinc deposit by extension of immersion time. This reflects that the porosity of the zinc coat is dimensioned and the energy of displacement is not enough to penetrates the zinc coat barrier by aluminum ion. After the stripe sample coated with zinc then immersed in distilled water bath follow by rinsing with distilled water to remove excess zincate solution then dryed at 110^{o}C. zinc coat stripped with nitric acid solution (50% by volume) at room temperature [8,9] until complete removal of zinc coat followed by rinsing with hot demineralized water (70 – 80^{o}C) for one minute to remove any traces of residual acid or salt formed from the treatment. The dry weight loss before and after stripping process resemble weight of zinc coat. The results show that zinc film was ~21 microns and the dissoluted thickness of aluminum alloy was 3.26 microns (ignoring the thickness of natural aluminum oxide film present which is in order of few angstromns and its weight). The thickness loss of aluminum was ~ 0.32% comparing with ~10% loss by mechanical process (using steel brushes), thus immersion coating has no effect on the strength of the stripe as in case of mechanical cleaning process and is very suitable for obtaining high aluminum oxide free surface [9 – 11].

The electrical resistance of the new clean aluminum alloy surface is studied as a function of time [zero time is the time at removal (stripping) of zinc coat] (Table 2). The average electrical resistance at zero time = 3.5 microhms while for pure aluminum is 2.6 microhms , this increament between the two values may be due to the presence of alloying elements (Mg, Cr, Fe, Si….) which have higher resistance than pure aluminum. The measured resistance values which is the resistance of the fresh natural aluminum oxide film formation was an a range value (Table2, Column 4), this may be due to the porosity of the formed film, which behave as discontinuous film results in a non sharp values.

Plotting of electrical resistance Vs. time (Figure 2) shows straight line, obey the equation.

$Y = 0.6X + 3.5$……………………………………………..(5)

The intercept = 3.5 microhms = the electrical resistance at t= 0 (after removal of the zin coat directly).

Slope = 0.6 microhm /hr. = rate of aluminum oxide film formation = change in electrical resistance withen the time.

Deviation from linearity starts after 30 hours from the removal of zinc coat (Figure 2), indicates that the rate of natural aluminum oxide formation reaches zero and the electrical resistance tends to be constant i.e. no porosity remained in the natural film which permits to the oxygen of the air to enter the alloy or to the aluminum ion to diffuse to alloy surface to from the oxide. Experimentally welding continues in success up to 48 hours (Table 2).

From the diameter of the welding spot and the ruptur's force of the welding spot which are given digitally by the welding machine as well as the electrical resistance, the tensile strength of the welding spot is calculated and the results compare with that provided by the welding machine company (unknown method) are listed (Table 3).

Table 3: Shows the tensile strength of the welding G_3/ 5052 aluminum alloy comparing with the data provided by welding machine company(last line in Table).

Time after remove of zinc coat hr.	Rupture's force of welding point kg	Area of the welding point mm^2	Tensile strength of the welding kg/mm^2
0	650	44.2	14.7
3	800	41.3	19.37
6	800	50.2	15.9
18	870	56.7	15.3
24	750	50.2	14.9
48	780	56.7	13.7
Unknown preparing method	502	25.52	19.67

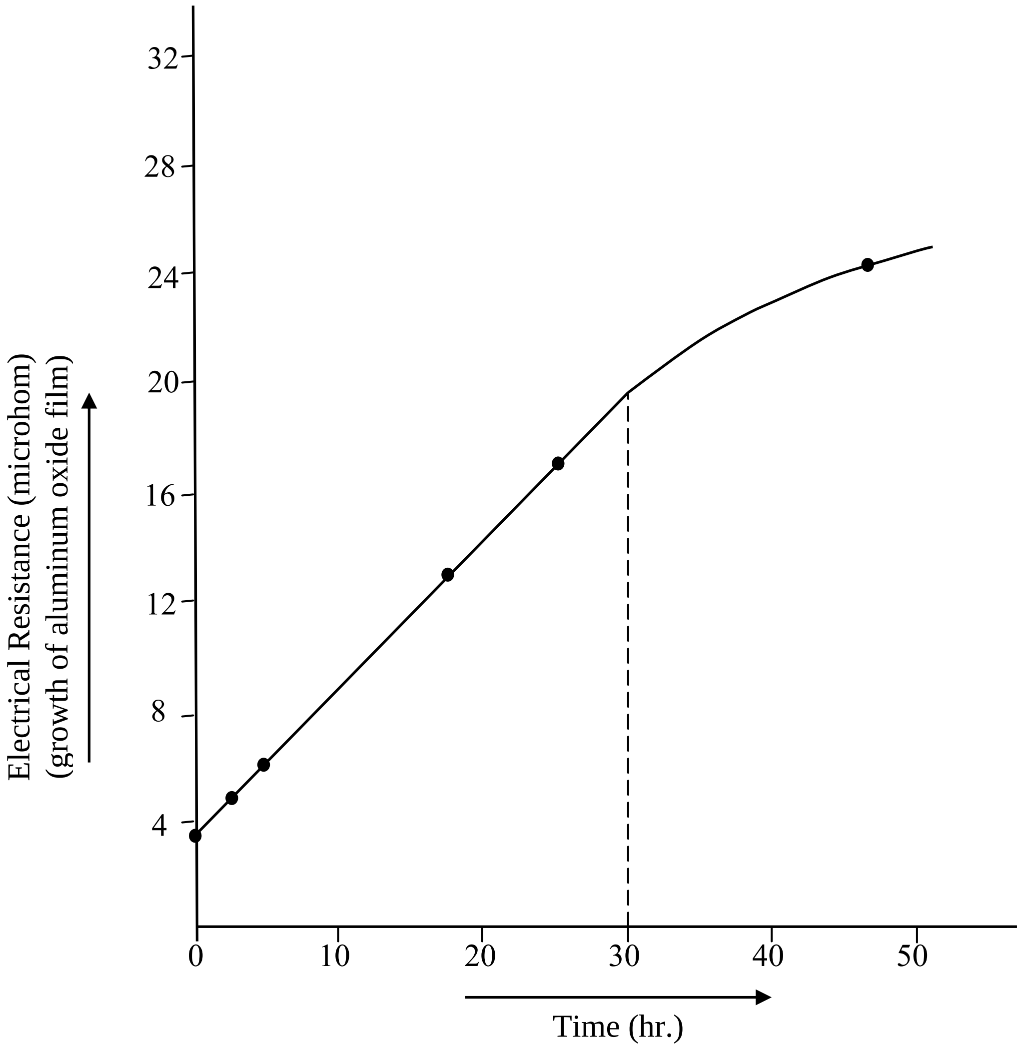

FIG. 2 ELECTRICAL RESISTANCE (mean values)VS. TIME FOR ALUMINUM ALLOY TYPE G_3/ 5052

Plotting tensile strength of the welding against the time after removal of zinc coat (Figure 3) shows a jump value for the tensile at t=3 hours, the values was 19.37 kg/mm^2 which is very close to that supply by the welding machine manufacturer 19.67 kg/mm^2 (of the unknown procedure for preparation of aluminum alloy surface to spot welding). The highest value (19.37 kg/ mm^2) obtained may be attributed to the nature of the oxide film formed during the three hours of zinc removal, such film has high porosity, low density, very thin, and freshly formed. From the increasing sample weight during the first three hours (weight of oxide film formed) calculation shows that the thickness of the oxide film in the order of 10^{-8} cm. Thus current will pass through the pores the easier way comparing with the electrical insulator aluminum oxide, thus aluminum underneath the oxide film will be near melting (plastic flow) taken with it the very thin and low quantity oxide film which behaves as flux for this process results in large spots areas (large faying area between the two weld surfaces), such areas nearly twice that area in case of unknown procedure given with the welding machine as well as the ruptur's forces in this work nearly 1.5 time that given with the machine (Table 3). The higher spot area and the higher rupture's force make the fault in ruptur's force test comes from the rupture of the alloy stripes not from the weld spot itself. From Table 3 column 4 (values are average of two readings), a conclusion rises that high performance spot welding required an optimum specifications of aluminum oxide film such that formed after three hours (19.37 kg/mm^2) from the exposure of the alloy surface to the atmosphere comparing with the absence of this oxide film at zero time (14.7 kg/mm^2) and with more thick oxide film starting from

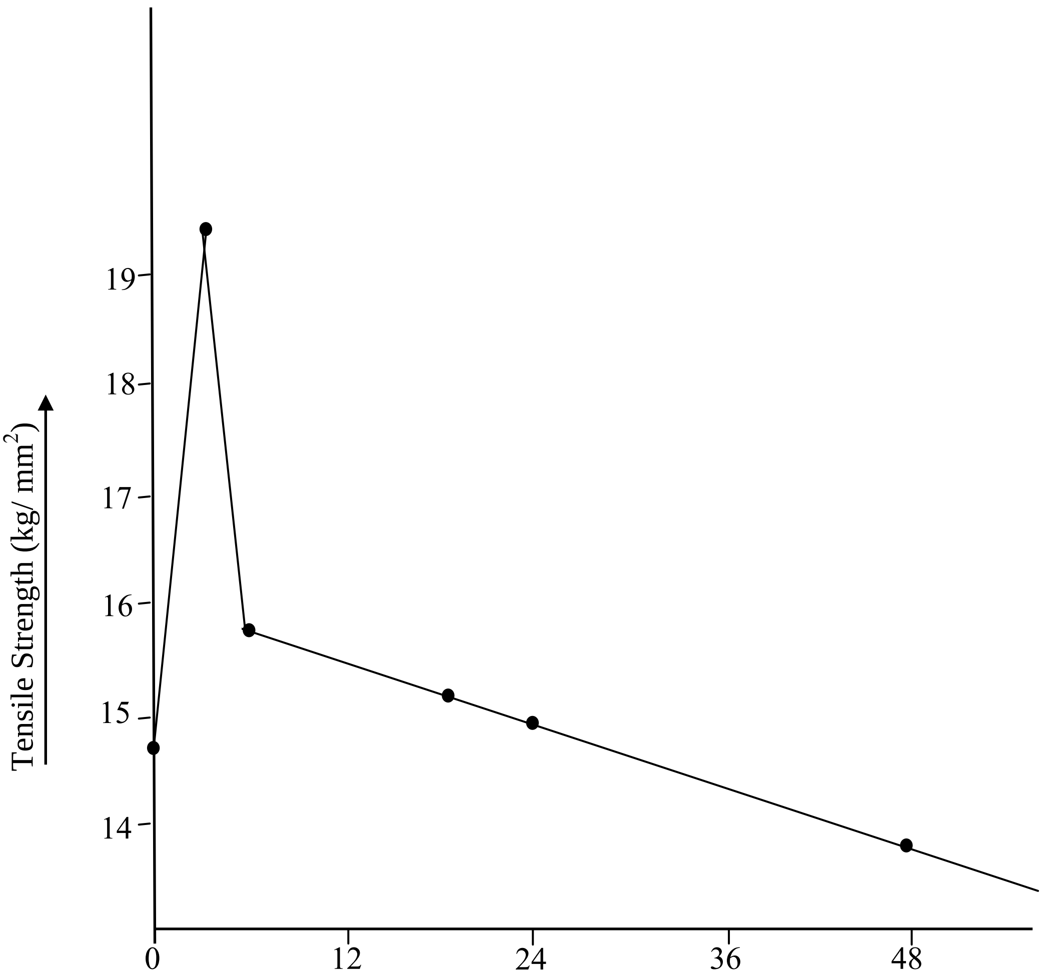

FIG. 3: TENSILE STRENGTH VS. TIME BEFORE WELDING PROCESS FOR ALUMINUM ALLOY TYPE G_3/ 5052

the reading six hours (15.9 kg/mm^2) and more until 48 hours (13.7 kg/mm^2) after that no more welding performance occurs.
Also Figure 3 shows that a linear relationship between tensile strength and time starting at 6 hours from removal of zinc coat up to 48 hours according to the equation

$$Y = - 0.053X + 16.23 \quad \ldots\ldots(6)$$

When X=6 $\rightarrow$ 48 hours exposing the surface of aluminum alloy to the atmosphere.
A5/3003 aluminum alloy shows similar behavior, thus a similar discussion that given previously for the G3/5052 alloy could be applied for the results of A5/3003 alloy.

Conclusions

1- zinc immersion coating as alkaline zincate solution is suitable for high performance spot welding technology for aluminum alloys types G3/5052 and A5/3003 as well as for studying aluminum oxide growth on these alloys.

2- The alkaline zincate solution is the most economic one for this purpose and it is not poisonous solution.

3- High performance spot welding required an optimum specification of aluminum oxide film such that formed after three hours (max value obtained, 19.37 kg/mm^2) from the exposure of the alloy surface to the atmosphere comparing with the absence of this oxide film at zero time exposure (14.7 kg/mm^2) or more thick oxide from 6 – 48 hours exposure.

4- There is a chance to store coated aluminum alloy parts before welding. This increases the productivity of welding lines comparing with others non-coating methods such as mechanical or chemical processes.

5- No effect on the thickness of the part, only 0.32% loss (original thickness 2mm) while about 10% loss by mechanical method.

6- 10% by weight solution of HCl or NaOH shows insufficient ability to meet the requirement for aluminum alloy spot welding

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