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Studies on the Corrosion of 13% Chrome Steel

By

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Part 1. Corrosion in non-oxidizing reagent

Abstract

Weight loss by corrosion of Fe-Cr system alloys in 10% sulphuric acid is measured and herein described results are obtained. The weight loss by corrosion, at first, increases gradually with the chromium content, however, at about 13% Cr., it changes suddenly and thereafter it changes gradually until about 18% Cr. When the chromium content of the alloy increases, in spite of the abnormal behavior of the corrosion, the natural electrode potential shows little change.

To make sure of the cause of such changes, polarization curves are measured and the following results are obtained. The corrosion reaction of these alloys in air saturated sulphuric acid represents cathodic control. The corrosion is also controlled by diffusion of oxygen. The increase of the corrosion velocity is due to the parallel displacement of polarization curve of local cathode towards the higher current density side. These results are discussed and this mechanism is explained as follows: Oxide film which forms the cathodic area, is stabilized at more than about 12% Cr. Accordingly, the area of the local cathode is increased and the polarization curve of the local cathode shifts towards the right. This consideration can also apply on the interpretation of the fact that the abnormal behavior which is found in sulphuric acid, is not observed in hydrochloric acid. In view of this consideration, the general film theory is useful in explaining the electrochemical behavior of 13% chrome steel.

§ 1. Introduction

Many workers⁷⁻¹²⁾ have studied on the corrosion of 13% chrome steel in oxidizing reagents. Studies on the corrosion in non-oxidizing

reagents are relatively few, however, such studies are important because they may give information on passivation.

The weight loss by the corrosion of chrome steel in sulphuric acid has been studied by Endo¹⁾ and by Murakami and Sato²⁾. The former has shown that weight loss by corrosion greatly increases when the chromium content of the samples is increased, however, no special phenomenon is found. On the other hand, the latter have shown a speciality at about 12% Cr. But they have not explained this phenomenon and have concluded that the weight loss rises with the increase of chromium contents. At first, to make sure whether or not the steep ascent of the weight loss curve at about 12% Cr. is due to some error of the experiment, the same experiment is carried out on weight loss in chrome steel due to corrosion by sulphuric acid.

§ 2. Experimental method and result

Samples are made from electrolytic iron and low carbon ferrochrom. They are melted together in alumina crucible in a high frequency furnace. Thereafter, by repeated rolling and annealing, platelet samples are made. These samples are annealed at 850°C for 4 hrs. and cooled in vacuum furnace. The samples are polished with abrasive paper until 0/4.

(A) Weight loss by corrosion and natural electrode potential.

About 4 cm² of the surface of the sample is bared, the remaining part is covered with an acid-proof paint and wax and dipped in 10% sulphuric acid to measure the weight loss by corrosion. The temperature is held at 20°C and agitation is not used. The natural electrode potential is measured during 3 hrs., after which period the electrode is taken out from the solution and washed with distilled water, dried and weighed. The apparent area and weight loss are measure and the weight loss per hour is calculated. At first, the potential changes relatively fast to the noble state, but after about 20 min. the potential becomes almost constant. This stable potential and weight loss are shown in Fig. 1.

The results of Murakami and Sato²⁾ are also plotted in this diagram. It is obvious from the comparison of these results, that the absolute values show differences, but the two curves have the same tendency. That is to say, the weight loss rapidly increase at about 12% Cr. and afterward the losses do not show any great change until about 18%

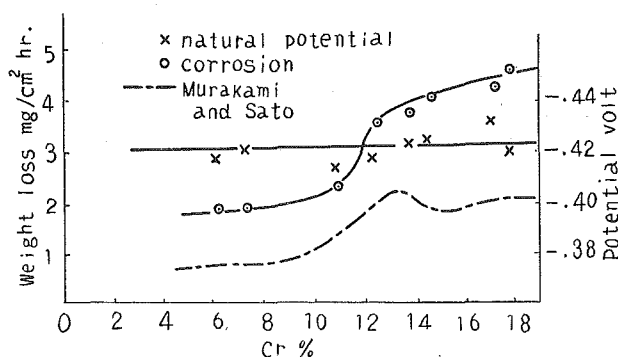


Fig. 1. Corrosion and natural potential of Fe-Cr alloys in 10% sulphuric acid.

Cr. On the other hand, natural electrode potential does not show a special change in this region. The difference of the values of the weight loss in these two curves may be due to the experimental conditions. In spite of this difference, the same tendency is observed in the two curves. From this result, it may be certain that a change of the factor which controls the corrosion velocity, may occur at about 12% Cr. One of the main objects of the present investigation is to make sure of this factor. For this purpose, the polarization curves are measured.

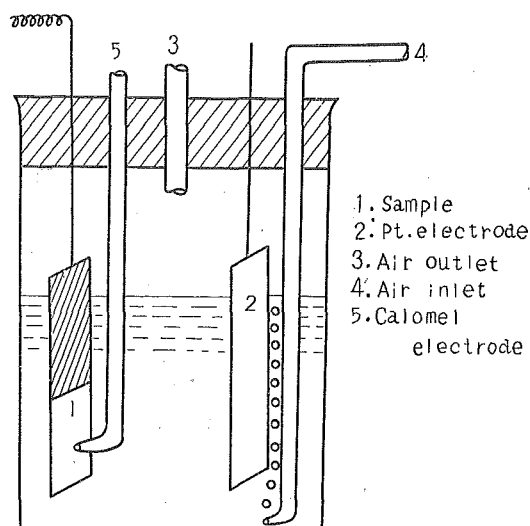


Fig. 2. Polarization cell.

(B) The measurement of the polarization curve.

To determine the polarization curve of this sample, the next assumptions are used: The corrosion is virtually electrochemical and the reaction proceeds by single galvanic couples. These assumptions may be approximately applicable to this case.

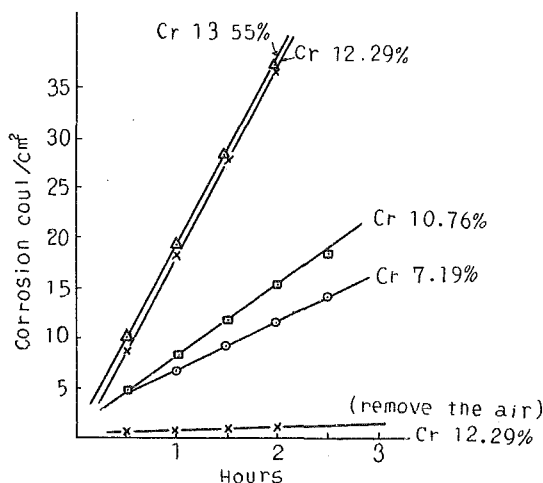


Fig. 3. Corrosion velocity of Fe-Cr alloys in air saturated 10% sulphuric acid.

At first, the relation between the natural electrode potential and corrosion velocity is measured. The cell which is used in this experiment, is shown in Fig. 2.

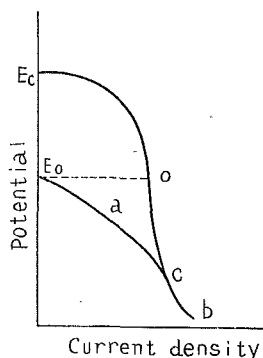


Fig. 4. Schematic illustration of the cathodic polarization curve.

During the measurement, the cell is maintained at 20°C and the solution is stirred and aerated by the air which is bubbled through the solution. Experimental results are shown in Fig. 3.

In this diagram, the amounts of the corrosion are represented by the electric quantities. In this corrosion, it may be considered that iron dissolves as bivalent state and chromium dissolves as trivalent state, so that those electric quantities are calculated by these assumptions. Except for the first 30 min., corrosion velocity is almost constant, hence the corrosion-time relation is linear. From the slope of this line,

the mean corrosion velocity is obtained.

Next, the cathodic polarization curve is measured in the cell shown in Fig. 2. In this case, the sample is connected to the cathode and platinum to the anode. Saturated calomel electrode is used as the reference electrode. The current is applied and instantly the potential is measured and the next current is applied. The measurement is repeated, by use of a higher current density. The measurement must be carried out as quickly as possible to avoid the change of the potential by the contamination of the surface of the sample.

Now, if the polarization curve of the local cathode is shown hypothetically by E_o, o, c, b , in Fig. 4, the cathodic polarization curve which is measured by this procedure is considered as E_o, a, c, b .

Therefore the line which connects o and c , is considered as the approximate polarization curve of the local cathode. Accordingly, the

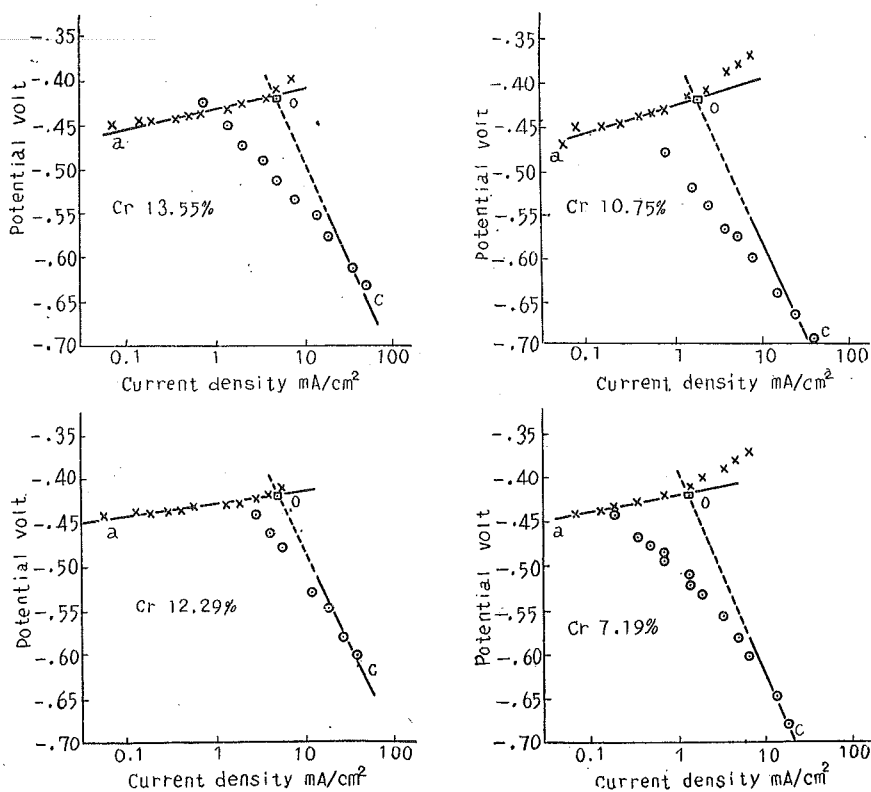


Fig. 5. Cathodic and anodic polarization curve for Fe-Cr alloys in 10% sulphuric acid.

cathodic polarization curve may be obtained by the application of this method. The results are shown in Fig. 5.

In this diagram, the mark $\odot$ is the measuring point and mark $\blacksquare$ is obtained from natural electrode potential and corrosion velocity which is obtained from Fig. 3. That is to say, oc may be considered as the cathodic polarization curve of the local cathode of this sample.

Next, anodic polarization curves are measured. Experimental apparatus is shown in Fig. 6. Prior to the experiment, the electrolyte is boiled and cooled in hydrogen atmosphere and then pre-electrolyzed.

The small platinum electrode which is seen in the lower part of in Fig. 6 and netted platinum electrode are used as cathode and anode, respectively.

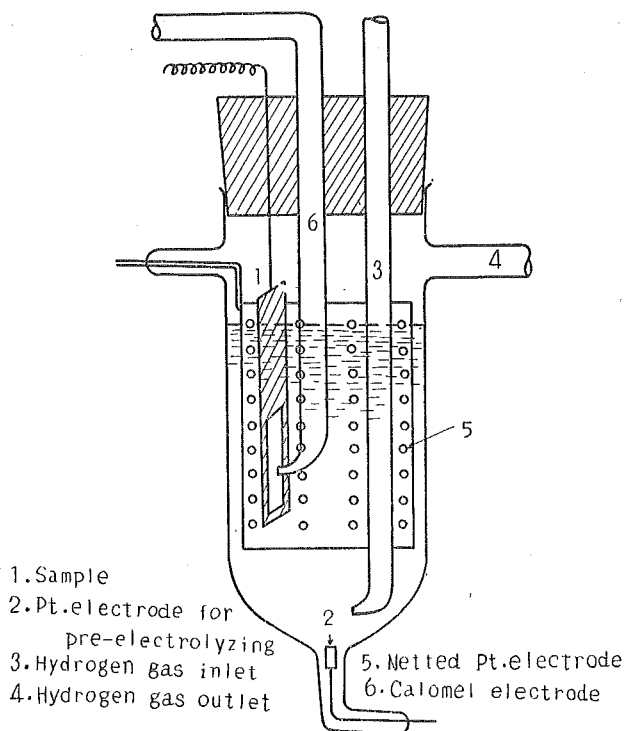


Fig. 6. Polarization cell.

One of the objects of this pre-electrolyzing is to remove the residual oxygen in the electrolyte. In this case, the anode area is large enough, therefore the potential does not reach the oxygen-evolution-voltage and only $H^2 \rightarrow H^+$ reaction occurs. Then the sample is set in

the cell. Anodic polarization curve is measured by use of a netted platinum electrode as cathode. Data obtained from the measurements are indicated in Fig. 5 by mark $\times$. This curve passes almost through the point which is marked by $\blacksquare$. Corrosion velocity of 12.29 pct. chrome steel is shown in Fig. 3. It is obvious from this figure that when the dissolved oxygen is removed from the electrolyte, the corrosion velocity becomes negligibly small. Therefore it is possible to consider approximately speaking that the local cell action is almost stopped and the curve which is observed, may be considered as the polarization curve of the local anode. Then, the polarization curves of local cathode and anode for each samples respectively are gained as is shown in Fig. 5.

To sum up, the following results are obtained:

1. The inclination of the anodic polarization curve is small, therefore this corrosion reaction is cathodic control.
2. As is shown in Fig. 3, this reaction is also controlled by diffusion of oxygen.
3. Inclination of cathodic polarization curve is almost the same in all samples.
4. Inclination of the anodic polarization curve is so small that no difference of natural electrode potential values is observed, in spite of the great difference of the corrosion velocity.
5. Corrosion velocity changes in accordance with the parallel displacement of the cathodic polarization curve.
6. The cathodic polarization curve moves suddenly towards the right when the chromium content of the sample is more than about 12%.

§ 3. Discussion

Uhlig³⁾ has explained the mechanism by which passivity is destroyed non-oxidizing reagent. Hydrogen is liberated at the surface of the passivated metal which is dipped in non-oxidizing reagent. A part of this hydrogen evolves to gas and remainder diffuses into the metal lattice. This atomic hydrogen decomposes to the electron and proton. This electron enters into the d-band hole of chromium and destroys the passivity. On the other hand, Evans⁴⁾ has opposed this theory. That is to say, if a 13% chrome steel loses the reactivity itself, it must be inert against all reagents, however the 13% chrome steel corrodes more rapidly than iron in hydrochloric acid. Therefore

Uhlig's theory would not explain the chemical facts. Heumann⁹⁾ discussed these theories and could not conclude that electron configuration as conceived in Uhlig's theory exists or not, because the saturation magnetism of Fe-Cr system alloys had not been measured. After all, if the electron configuration as in Uhlig's theory does not occur, it is possible to consider that some configuration occurs in the alloy, because the magnetic curie point vs. composition relation of Fe-Cr equilibrium diagram⁶⁾ is not constant.

As is shown in Fig. 5, corrosion velocity is controlled by the cathodic polarization and is changed by the parallel displacement of this curve. Roughness factor, and diffusion velocity of oxygen are considered as the factor which cause variation in the polarization curve. But these are almost the same in all samples because experimental conditions are the same. It is most reasonable to assume that the area of the local cathode has changed. In this case, the local cathode may be considered to consist of the part which is covered by the oxide film. In this redusing condition, the area of the local cathode is expected to be very small as compared with the area of the local anode. Therefore, large change of the area of the local cathode has almost no effect on the area of local anode. From Evans' theory, the oxide film of the alloy with more than 12% chromium, becomes so rigid and stable that the possibility that the film is produced and fixed on the surface of the electrode, suddenly increases at about this composition. Accordingly, the area of the local cathode is increased and cathodic polarization curve shifts towards the right at more than 12% chromium content. Also in the hydrochloric acid, such tendency was not observed²⁾ because chlorine ion strongly destroys the oxide film. This tentative consideration is supported by the fact²⁾ that the corrosion velocity of Fe-Cr system alloys in 10% hydrochloric acid is smaller than that in 10% sulphuric acid. It is very difficult to explain these facts by the electron configuration theory³⁾. Therefore in this consideration, Evans' general film theory is more useful in explaining the facts than is the electron configuration theory.

§ 4. Summary

1. The weight loss by corrosion of Fe-Cr system alloy in 10% sulphuric acid, gradually increases with its chromium content at first and rapidly increases at about 13% chromium and thereafter continues

a gradual increase again.

2. In this case, natural electrode potential does not change with its chromium content.

3. The corrosion reaction of the alloy in air saturated sulphuric acid is cathodic control.

4. The corrosion is also controlled by diffusion of oxygen.

5. Oxide film is stabilized at more than 12% chromium and area of the local cathode is increased, accordingly, polarization curve of the local cathode shifts towards the higher current density side.

6. This consideration can apply to the corrosion behavior of this alloy in hydrochloric acid.

7. The general film theory supports this consideration.

Part 2. Corrosion in oxidizing reagent

Abstract

To make sure about the question why the passivation of Fe-Cr system alloy is stabilized from about 1/8 atomic pct. chromium, the present studies are carried out. Iron-chromium alloys with 6 to 18 pct. chromium are made; natural electrode potential of these alloys in nitrate, nitric acid and HgCl_2 solution are measured. From these results, it is shown that one main cause of the excellent corrosion resisting property of the alloy with more than 13 pct. chromium, may be due to the rapid decrease of its critical current density which is necessary to cause passivation. Therefore the alloy with more than 13 pct. chromium is easily passivated by small local currents.

The critical current density for passivation is measured in 1/20 N nitric acid solution and the following relation is found between critical current density I and mol fraction of the alloy x .

$$\text{Log } I = ax + b$$

Anodic polarization curve at constant current density is measured by oscillographic method. When the current density is in the order of $10^{-2} \sim 10^{-4}$ amp/cm², trivalent dissolution of chromium is observed in the alloy with less than 13 pct. chromium, however, hexavalent dissolution immediately occurs in the alloy with more than 13 pct. chromium. The amount of coulombs/cm² needed for passivating is decreased by increase of chromium content until about 13 pct. chromium;

from this composition the amount becomes constant to the values of 3 millicoulombs/cm². From this finding, it is reasonable to consider that a monolayer of oxygen may be adsorbed on the surface of the passivated alloy. In conclusion, it must be considered that, even if there is not a change of electron configuration as is shown by Uhlig, some change would exist in the alloy itself.

§ 1. Introduction

Thirteen pct. chrome steel is known as a basal alloy of stainless steel. In company with the increase of the commercial application of stainless steel, many studies⁷⁻¹²⁾ on the passivation of 13 pct. chrome steel have been carried out. The corrosion resistance of this alloy is due to the passivation, therefore the alloy with not less than 13 pct. chromium has strong resistance only in the oxidizing reagent. Fe-Cr system alloys are homogeneous α solid solution alloys at about 13 pct. chromium.

Therefore from the standpoint of "parting limits¹³⁾" the question arises why the passivation is stabilized from about 1/8 atomic pct. chromium. Evans⁷⁾ has shown that the chromium content of the oxide film, which is formed on the surface of the passivated alloy, reaches sufficient amount from about 13 pct. chromium. On the other hand, Uhlig⁸⁾ has explained the situation the electron configuration theory. The main object of the present study is to make sure of the relation between the composition and passivation of this system alloys.

§ 2. Natural potential in oxidizing reagents

(1) Natural electrode potential in nitric acid.

Electrolytic iron and low carbon ferro-chrome are melted together in the high frequency furnace, and rolled. Platelet samples of 70 mm length, 10 mm width and 0.3 mm thickness, are made. These samples are annealed in vacuum furnace at 900°C × 3 hrs., then slowly cooled to 800°C, and then quenched in water. γ region of this alloy lies at about 800°C⁶⁾, therefore uniform α solid solution may be obtained by this heat treatment. Results of the analysis of the samples are shown in Table 1.

The sample is polished with abrasive paper until 0/4 and then electropolished by use of an electrolyte (perchloric acid + acetic anhydride). About 1.5 cm² of the surface the sample is bared and the

TABLE I. Composition of the samples.

Sample No.	Cr mol %	C wt %	Si wt %
1	6.47	0.082	0.09
2	7.68	0.051	0.07
3	9.41	0.037	0.15
4	11.18	0.078	0.09
5	11.45	0.035	0.08
6	13.08	0.052	0.13
7	13.88	0.025	0.15
8	14.40	0.045	0.07
9	15.31	0.034	0.17
10	18.01	0.028	0.10
11	18.68	0.066	0.22

other part is covered with wax.

At first, natural electrode potential in nitrate is measured to compare with other data. The results of measurement are shown in Fig. 7.

This curve has the same tendency with the data secured by the measurements made by Heumann and Rösener¹⁰⁾ in potassium nitrate solution. That is to say, the potential increases with the increase of

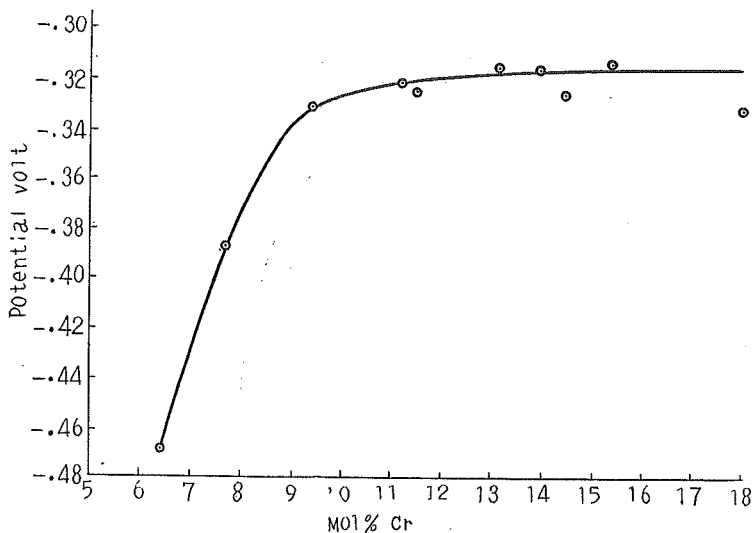


Fig. 7. Natural electrode potential of Fe-Cr alloys in 10% KNO_3 + 1/50 N, HNO_3 solution at 17°C.

chromium content until 10 pct. chromium, however, the alloy with more than 10 pct. chromium, has almost the same potential. This seems to show that a slight change of its impurity is not an important factor influencing the potential of Fe-Cr system alloy in oxidizing reagent.

It has been known¹³⁾ that weight loss by corrosion of Fe-Cr system alloys in nitric acid solution, decreases suddenly from alloys having more than about 13 pct. chromium. Next, natural potential in 1/5 N nitric acid is measured. The obtained results are shown in Figs. 8 and 9. From Fig. 8, it is noticed that in early stage, the potential has the same tendency with that which is shown in Fig. 7. However, as is shown in Fig. 9, the potential of the alloy with more than 13 pct. chromium, thereafter suddenly increases and the corrosion stops. On the other hand, the potential of the alloy with less than 13 pct. chromium does not change, therefore the corrosion advances.

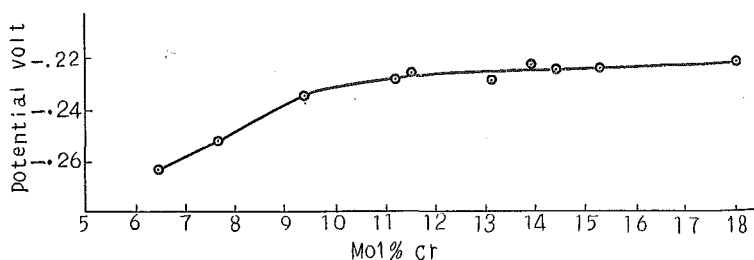


Fig. 8. Natural electrode potential of Fe-Cr alloys in 1/5 N HNO_3 solution at 17°C (after 80 min).

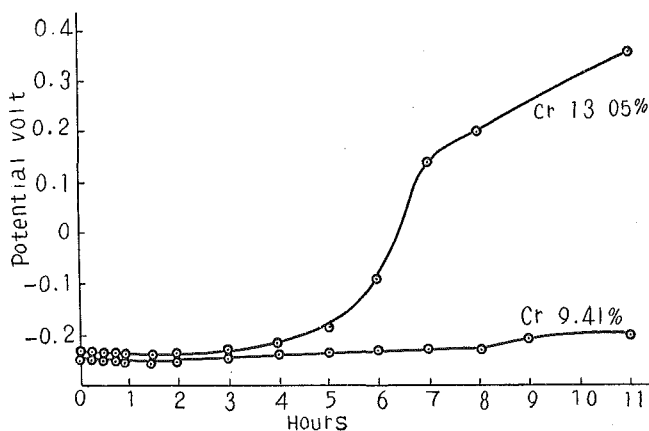


Fig. 9. Potential change of alloys in 1/5 N HNO_3 solution at 17°C.

(2) Natural electrode potential in HgCl_2 .

It has been reported²⁾ that the corrosion of Fe-Cr system alloys in HgCl_2 solution decreases suddenly from more than 13 pct chromium. The natural potential of the alloy in 1 pct. HgCl_2 solution is measured. The results are shown in Fig. 10.

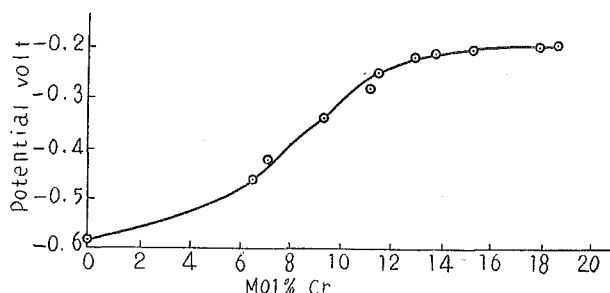


Fig. 10. Natural electrode potential of Fe-Cr alloys in 1% HgCl_2 solution at 20°C.

HgCl_2 is not as strong an oxidizing reagent as is nitric acid. However, many pits are found in the corroded surface, therefore, the alloys may be passivated by the strong local current.

§ 3. Critical current density in dilute nitric acid

Decrease of the corrosion of the alloy made with more than 13 pct. chrome in oxidizing reagent is due to the passivation which is produced by the local currents. Therefore the current which is necessary to cause passivation, is the important factor. The critical current density is measured in 1/20 N nitric acid. The experimental method is as follows: Cathodic treatment is carried out in 10 mA/cm² during 10 sec. Then the sample is maintained status in quod for about 30 min. until the open circuit potential attains steady values. Thereafter a certain current is applied and the maintained until the potential becomes almost constant. The potential is measured and the current is cut off. After the potential returns to the initial values, a higher current is applied and the operation repeated, until passivation occurs. This current density, at which the passivation occurs, is shown by × mark; the greatest current density at which the passivation does not occur is shown by ⊙ mark, in Fig. 11.

Therefore the critical current density must exist between these marks. In general, this critical current density is considered to be

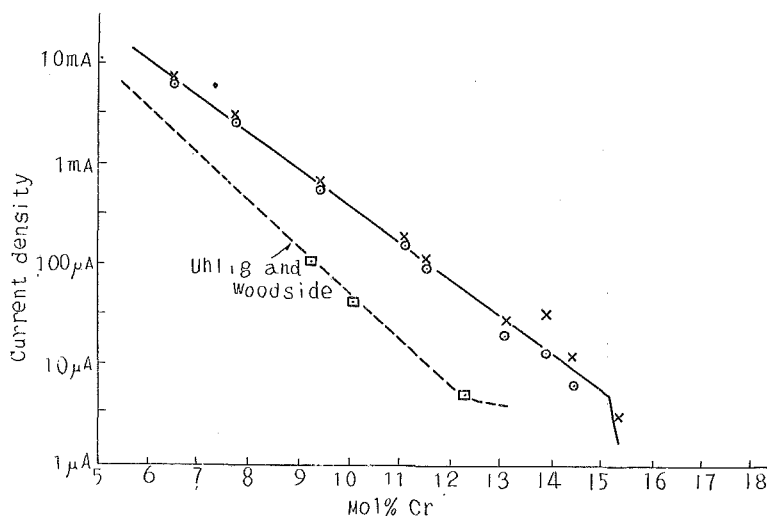


Fig. 11. Critical current density for passivity of Fe-Cr alloys in 1/20N HNO₃.

the apparent value which is changed by the electrolyte, temperature and another measuring conditions. However, when the measuring conditions are kept constant, this value shows good reproducibility. Therefore, these respective values can be compared with one another within one series of experiments.

As is shown in Fig. 11, the relation between composition and critical current density is represented by the following equation when the chromium content of the alloy exists within 6 to 20 pct.

$$\text{Log } I = ax + b$$

I : critical current density. x : mole fraction of chromium.

Critical current density as measured by Uhlir and Woodside¹¹⁾ in Na₂SO₄ solution, is also shown in Fig. 11 by the dotted line. In their paper, they have stated that the critical current density no longer exist in the alloy with more than 13 pct. chromium, but in the present study the critical current density is observed until about 15 pct. chromium. However, good agreements are obtained in both studies upon the fact that the critical current density decreases suddenly with the increase of chromium content.

§ 4. Oscillographic measurement of the anodic polarization

Anodic polarization curves in constant current density are meas-

ured by the oscillographic method. Uhlig and co-worker¹¹⁾ have measured by coulometry, the number of equivalents concerned with change from active to passive state. However, they used a small current density, hence, several minute were required to achieve passivity. By shortening of the time for passivation, the influence of the diffusion during the measurement may be diminished. Accordingly, more accurate results may be obtained in this case. For this purpose, a large current density is used and the potential change is recorded by oscillographic method. This equipment consists of a vacuum tube potentiometer, amplifier and 3-element oscillograph. Constant current is supplied from a high voltage battery and from a high resistance. The time and current are recorded simultaneously with the potential, on the oscillogram. After the reproducibility is confirmed, four degrees of current density are applied on each sample. The critical current density and applied current density are shown in Table 2. The values of coulombs/cm² are calculated from the time and the current in the oscillogram. The polarization curve (potential vs. values of coulombs/cm²) is shown in Fig.12. In this figure, at first the potential rises suddenly, when the current is switched on. This jump of potential is attributed to the charge of the electric double layer between the sample and electrolyte. This is shown by A in Fig.12. Thereafter dissolution occurs of iron and chromium in the sample and gradually the surface of the sample becomes saturate with their salts. This is shown by B in Fig.12. It is probable that a formation of a oxide

TABLE II. Applied current density.

Sample No.	Critical C. D.	I	II	III	IV	V
1	mA/cm ² 7.24	mA/cm ² 18.58	mA/cm ² 9.18	mA/cm ² —	mA/cm ² —	—
2	2.85 "	10.05 "	6.81 "	3.51 "	—	—
3	0.623 "	8.91 "	5.90 "	3.06 "	1.57 "	—
4	0.177 "	16.95 "	8.41 "	4.22 "	0.806 "	—
5	0.104 "	8.60 "	5.69 "	2.86 "	0.540 "	—
6	0.0239 "	7.45 "	4.95 "	2.50 "	0.470 "	—
7	0.0113 "	10.75 "	5.34 "	2.70 "	0.504 "	—
8	9.9 μ A/cm ²	9.20 "	6.10 "	3.10 "	0.601 "	—
9	<3.0 "	15.23 "	8.49 "	4.23 "	0.802 "	—
10	—	12.07 "	6.09 "	3.15 "	0.604 "	2.91 μ A/cm ²

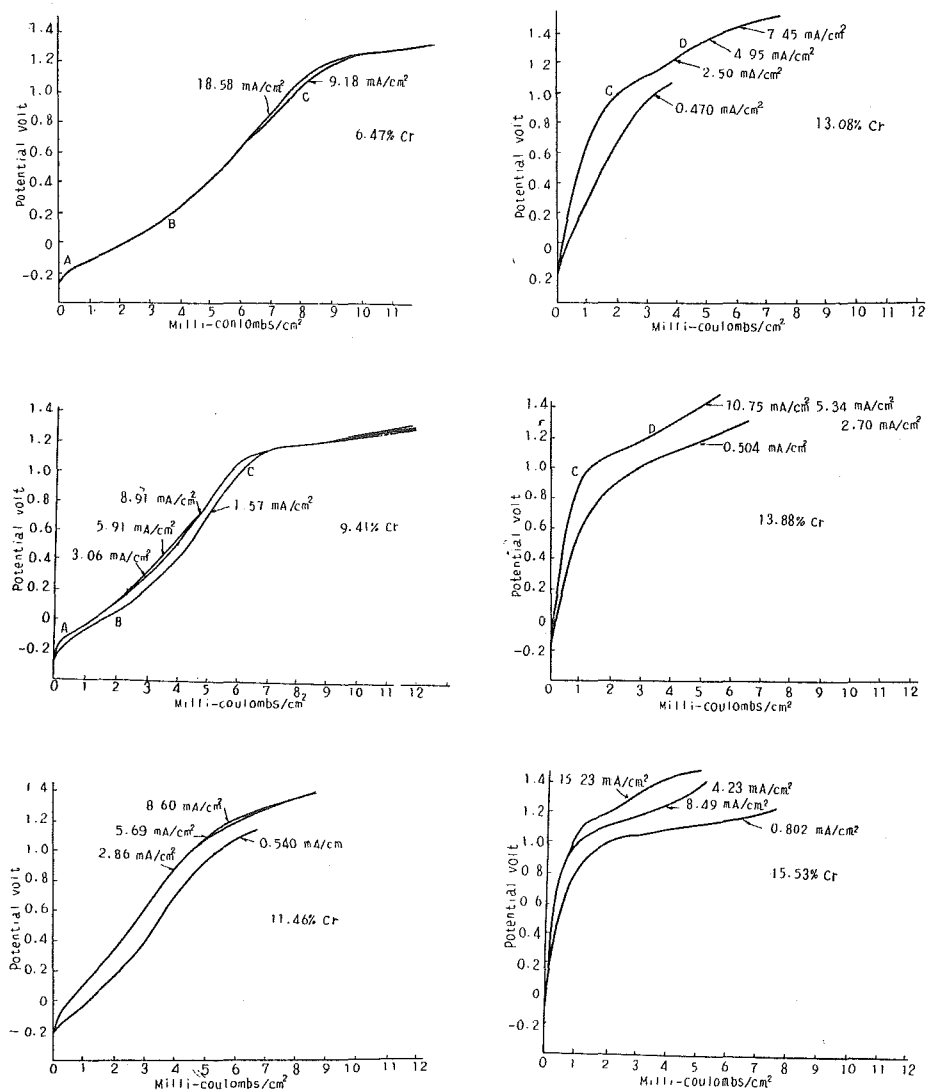


Fig. 12. Anodic polarization of Fe-Cr alloys.

film, starts at B, consequently the surface of the sample is covered by a porous film. Thereafter the current concentrates into the part which is not yet covered by a film. Then hole of the film becomes smaller and smaller. Therefore the potential rises very rapidly from B to C. At last, the oxide film will probably spread over the electrode surface. This point is shown by C. Until this stage is reached, iron and chromium dissolve as ferrous ions and chromic ions, respectively. But from this stage, they dissolve as trivalent and hexavalent ions, respectively. Thereafter the surface of the sample is covered by the oxide film after which oxygen evolution occurs. This point is shown by D. When the sample has less than 13 pct. chromium, the potential change which corresponds to the trivalent dissolution of chromium is clearly observed. But when the sample has more than 13 pct. chromium, this change is almost not recognizable and it is considered that the hexavalent dissolution of chromium occurs immediately. However, when the current density is less than 10^{-5} amp/cm², trivalent dissolution is observed in these alloys. Also in metallic chromium, it was reported¹⁴⁾ that the trivalent dissolution is observed in nitric acid at this current density. Therefore only when the current density is more than 10^{-4} amp/cm², is dissolution not observed in the alloy with more

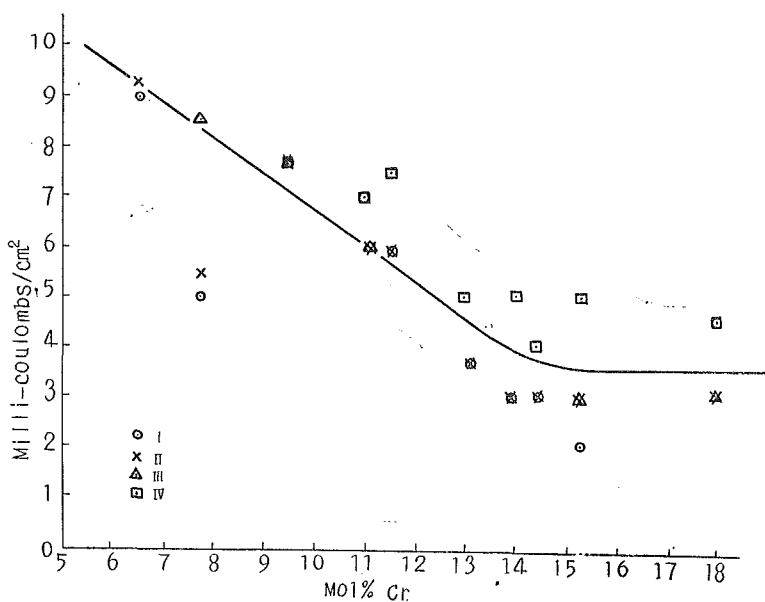


Fig. 13. The number of equivalents necessary to passivate.

than 13 pct. chromium.

The number of equivalents necessary to passivate the alloys is shown in Fig. 13.

In this case, the value of the coulombs/cm² is calculated from the time required to reach 1.2 volt vs. saturated calomel electrode. This amount is decreased by increase of chromium content of the alloy, but for the alloy with approximately more than 13 pct. chromium, this amount remains almost the same. This minimum value is about 3 milli-coulombs/cm².

§ 5. Discussion

The critical current density is considered to be defined as follows: When a current density rises, the electrode can not reach to the current density only by the ionization of the anode metal, and discharge of the negative ions begins to occur. The critical current density is about 200~300 mA/cm² for electrolytic iron and is a few μ A/cm² for chromium. Hence, the dissolution velocity of iron is greater enough than that of chromium. Therefore in the case of Fe-Cr alloy, when iron and chromium in the sample simultaneously dissolve in the same Fe-Cr ratio as the metal,

$$IX = L : I = L/X$$

L : dissolution velocity of chromium.

X : mole fraction of chromium.

I : anodic current density.

is obtained. For example, when the alloy has 10 pct. chromium,

$$1 \mu\text{A}/0.1 = 10 \mu\text{A}$$

That is, dissolution of chromium must be saturated in the order of 10 μ A/cm², but actual, chromium dissolves with iron even in few hundreds micro-amp. per sq. cm. From this fact, it is probable that chromium may be in a more soluble state and it may also be suggested that chromium has a different electron configuration in the alloy with less than 13 pct. chromium.

In the study of anodic polarization, it is noted that when the current density is more than 10⁻⁴ amp/cm², the potential change which corresponds to the trivalent dissolution, is not observed in the alloy with more than 13 pct. chromium. This tendency is also expected from the amount of coulombs/cm² required for passivation as is shown

in Fig. 13.

These facts suggest that an abnormal change of the passivation property may exist in about 13 pct. chromium. This discontinuous change is considered to be difficult to explain only by the continuous increase of the chromium contents of the oxide film which is formed on the alloys. Therefore, it must be considered—even if this is not a change of electron configuration as is shown by Uhlig³⁾—some change has occurred in the alloy itself.

Uhlig and co-worker¹⁾ have shown that the amount of coulombs/cm² needed for passivation is 14 milli-coulombs/cm² in spite of the chromium content of the alloy. Olivier¹²⁾ has reported that the whole equivalent to the amount of oxide formed is 8 milli-coulombs/cm². Both values are larger than that obtained in this study. The former has used a small current density in his study, therefore the effect of the diffusion during the measurement should not be negligible. The oscillogram of the latter worker shows a dissolution in the active state of the alloy, hence over-estimation may be expected in his amount. From the present study, the limiting amount of coulombs/cm² needed for passivation is 3 milli-coulombs/cm² which amount corresponds to about 0.3×10^{-6} gr. oxygen/cm². Now a monolayer of close-packed oxygen atoms corresponds to 0.15×10^{-5} gr./cm² true surface. Therefore a roughness factor of 2 would be required if one assumes an adsorbed monolayer of oxygen atoms. The roughness factor of 2 may be reasonable because this sample has been electro-polished.

§ 6. Summary

1. One main cause of the excellent corrosion resisting properties of the alloy with a chromium content of more than 13 pct. is the rapid decrease of the critical current density required for its passivation.

2. A logarithmic relation is found between the critical current density for passivation in 1/20 N nitric acid and mole fraction of the alloy.

3. When the current density is greater than 10^{-4} amp/cm², trivalent dissolution of chromium is observed in the alloy with less than 13 pct. chromium, however, hexavalent dissolution occurs immediately in the alloy with more than 13 pct. chromium in nitric acid.

4. The amount of coulombs/cm² needed for passivation is about 3 milli-coulombs/cm².

5. It is reasonable to consider that a monolayer of oxygen may be adsorbed on the surface of the passivated alloy.

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