THE EFFECT OF NICKEL ADDITION BY DIFFUSION ON THE MICROSTRUCTURE OF AISI 304 AUSTENITIC STAINLESS STEEL AND S.A. 212 FERRITIC STEEL

by

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INTRODUCTION

Considerable work has been done on atom migration in dissimilar metal joints at elevated temperatures. Such studies have been for the most part confined to welding in refinery, chemical and powerplant operations. When a ferritic steel is welded to an austenitic stainless steel, carbon migration across the welded interface at high temperatures produces a decrease in the properties of the metal joint. Strength decreases in the decarburized ferritic steel, while the austenitic stainless steel becomes embrittled as a result of carbide formation.

Various kinds of metals have been used as an intermediate layer between the two welded metals to reduce the diffusion rate of carbon from the high-carbon steel to the low-carbon steel. One of the metals which has been studied to determine its effectiveness as a barrier to carbon diffusion is nickel. However, at high temperatures, properties of steels have been found to be changed as the result of the migration of the substitutional nickel atoms. Nickel, as an alloying element, has long been known to depress the eutectoid transformation temperature of steels.[(1)] Also, nickel reduces the solid solubility of carbon in austenite and retards the rate of pearlite formation from austenite during the quenching of steels.[(2,3)] Thus, the effect of nickel on the structure of steels is an important consideration when used as a diffusion barrier between two welded steels.

Therefore a study was initiated to investigate the effects of nickel on the microstructure of S.A. 212 and AISI 304 austenitic stainless steels at elevated temperatures. Samples of both ferritic and austenitic steels were electroplated with nickel and then annealed for various periods of time at 1300°F.

II

LITERATURE REVIEW

The effectiveness of nickel as a barrier to the diffusion of carbon from a ferritic steel into austenitic stainless steel when exposed at elevated temperatures is of some interest. This diffusion of carbon causes a decrease in the structural properties of the bonded joint between the two steels. Therefore, any barrier to this diffusion is important.[4]

Diffusion between two dissimilar metals occurs when an alloy, such as a steel, with a thin layer of nickel plated on the surface, is heated to an elevated temperature. Diffusion of nickel into the steel will affect the structure and properties of the steel. Although some iron diffuses into the nickel during heating, the quantity is usually so small that no undesirable effects occur.[4]

When nickel is alloyed with iron in increasing proportions, the temperature of the allotropic transformation from the face-centered cubic form of iron to the body-centered cubic form is gradually lowered. At about 30 percent nickel, the transformation will be depressed to room temperature with the result that the body-centered phase no longer exists. Nickel not only depresses the eutectoid transformation temperature in iron but stabilizes the face-centered cubic austenite. With 30 percent nickel or more, iron-nickel binary alloys are completely austenitic at all temperatures.[1,5]

From the carbon-nickel phase diagram,[2] the solid solubility of carbon in nickel is 0.65 w/o at the eutectic temperature, $2400^{o}F$. This solubility decreases to about 0.25 w/o at $1750^{o}F$. Nickel, as well as chromium, is added to iron to decrease the solubility of graphite in austenite from about 1.3 w/o to about 0.1 w/o at $1750^{o}F$. Any carbon in excess of this amount would be present as a carbide. Nickel carbide, Ni_3C, containing 6.42 percent carbon has been found to exist between 1500 and $2500^{o}C$, but this carbide is endothermic and is very unstable. Gerds and Mallett[6] find no evidence of reaction between graphite and nickel at 1650 and $1850^{o}F$ except for a very thin layer of bright and obviously hard material at the interface. The increase in hardness in nickel near the graphite-nickel interface was concluded to be the result of carbon dissolved to the solubility limit, 0.25 w/o.

Even though there is no appreciable reaction of carbon with nickel at 1650 and 1850^{o}F, thermal cycling from a relatively low temperature up to 1700 or 1800^{o}F may end up with deterioration of nickel by a graphitization mechanism.[6] This mechanism is the result of carbon going into solution in nickel at high temperatures and the precipitation of carbon in the form of graphite at low temperatures. This graphitization can be greatly reduced by adding copper, which is known to decrease the solubility of carbon in nickel and the rate of graphite precipitation from supersaturated solid solution.

Since nickel is not a carbide former, it apparently does not greatly affect the diffusion rate of carbon in austenite. The diffusion rate of nickel, which is very much slower than that of carbon, is affected markedly by variation in carbon content.[2] The rate of diffusion of nickel in gamma iron in low-carbon and high-carbon nickel steels increased with nickel concentration; at first slowly and then more rapidly. The rate of diffusion is further increased by carbon. Wells and Mehl[7] have observed that if the nickel content in these steels is raised from approximately zero to 20 percent, the value of the diffusivity coefficient for nickel increases about 80 percent. Also they have shown that the rate of diffusion of nickel will increase almost linearly as the content of nickel and carbon increases up to 20 w/o and 1.5 w/o respectively. If the carbon concentration is raised from 0.03 to 1.5 percent, an increase of more than 300 percent in the value of the diffusivity coefficient of nickel will result.

Information about the reaction of nickel in stainless steels may be observed in the pseudo-binary systems of (Fe + 18% Cr + 4% Ni):C and (Fe + 18% Cr + 8% Ni):C.[1] With 4 percent nickel, stainless steels containing less than about 0.4 percent carbon are a mixture of ferrite and carbides at room temperature. In the presence of 8 percent nickel, the three-phase eutectoidal field of ferrite, carbide and austenite is depressed to still lower temperatures and carbon contents. A comparison of these two diagrams shows that a low nickel content in an Fe + 18% chromium alloy would tend to harden by martensite formation while high-nickel content alloys would tend to give a more stable austenite.

$(CrFe)_4C$ is the stable carbide found in the above alloys.[1] Since nickel is not a carbide-forming element, $(CrFe)_4C$ may be presumed to be the carbide in 18:8 stainless steel. Brick and Phillips[1] have mentioned that above the A_{cm} there is a minimum of 70 percent chromium in the carbide phase and only 18 percent chromium in austenite. Precipitation of chromium carbides results in the depletion of chromium in the remaining austenite.

An increase in alloy content, such as nickel, would materially increase hardenability in steels. Examination of the appropriate equilibrium diagrams[8] reveals that an addition of sufficient nickel to carbon free iron produces the gamma phase at temperatures where only the alpha phase of pure iron is stable. This again amounts to the statement that nickel lowers the eutectoid temperature.[9]

When nickel is introduced in amounts up to approximately 5 percent in ferrite the strength and hardness are increased without inducing a comparable reduction in ductility. Beyond this amount, the strength and hardness of ferrite increase more rapidly and a martensitic-like structure begins to appear even in the alloys which have been slowly cooled.[2]

To study diffusion across dissimilar metal joints, Eckel[10] performed an experiment by interposing a thin sheet of high purity nickel between a ferritic and an austenitic stainless steels. As a result, a band showing indications of ferrite with carbide precipitation was formed between nickel and austenitic stainless steel. This band was presumed to have formed as a result of carbon diffusion from the ferritic steel through the nickel barrier to the austenitic stainless steel. A martensitic band was formed between the nickel and the ferritic steel.

III

EXPERIMENTAL PROCEDURE

The object of this investigation was to study the effect of nickel upon the microstructure of S.A. 212 ferritic and AISI 304 austenitic stainless steels. The specimens, plated with a thin layer of nickel, were annealed at 1300^{O}F and phase changes near the interface as a result of diffusion were analyzed by standard metallurgical techniques.

Preparation of Specimens

Specimens used in this investigation were prepared by machining bars of AISI 304 austenitic stainless and S.A. 212 ferritic steels into cubes approximately one-half inch to a side. All specimens were polished to produce smooth surfaces. Before electroplating, the stainless steel specimens were activated in a 25 percent sulfuric acid solution for one minute; then washed in a 0.1 percent hydrochloric acid solution for 30 seconds to remove the passive film present on the stainless steel which would prevent adhesion between the nickel plate and the stainless steel surface.

All specimens were then electroplated in a bath of purified nickel sulfamate solution. The time of electroplating was seven hours for the austenitic stainless steel and six hours for the ferritic steel. The electroplating process was carried out in a 600 millimeter beaker with a thin strip of 99.97 percent pure nickel as the anode. Effective current densities applied during plating were 300 and 380 milliamperes for the austenitic stainless steel and ferritic steel specimens, respectively. The thickness of the nickel film was determined by averaging measured thicknesses at various positions along the interface with an optical micrometer. The average thickness of the nickel film was 0.30 and 0.34 millimeters for the austenitic stainless steel and ferritic steel specimens, respectively.

Following the electroplating process, all specimens were encapsulated in evacuated fused quartz tubes. Two specimens, one austenitic stainless steel and the other a ferritic steel, were encapsulated in each tube so that each series of samples would be given the identical treatment. Encapsulated specimens were then heat treated at 1300°F to allow diffusion to occur. Specimens were held at this temperature for times ranging from 50 hours to 4000 hours (approximately 2 days to 6 months).

After removing from the furnace and air cooling, the specimens were mounted for metallographic studies. They were polished and etched according to standard metallographic techniques. The etchants used were 5 percent nital for the ferritic steel and an electrolytic etch of 10 percent chromic acid for the austenitic stainless steel. Metallographic examination indicated that phase changes had occurred at the dissimilar metal interface as a result of diffusion.

Micro-hardness measurements were made on the diffusion couples which were annealed for 4000 hours. Measurements were made in the area of the diffusion bands. The Bergsman's micro-hardness tester utilizing a five gram load was used for making these measurements.

IV

RESULTS

Diffusion couples between nickel and S.A. 212 ferritic steel and between nickel and AISI 304 austenitic stainless steel were annealed for various times at 1300^{o}F to observe the effect of nickel on the structure of ferritic and austenitic steels.

After diffusion, voids were observed on the nickel side of both the nickel-S.A. 212 and nickel-AISI 304 diffusion couples indicating that migration of nickel into steels occurred. A distinct band was formed at the dissimilar metal interface in both diffusion couples. The structure of the band in the nickel-S.A. 212 diffusion couple is acicular in appearance. The acicular nature of this band is clearly shown in Figure 4 and 5 and was identified as martensite. The band formed between nickel and AISI 304 was identified by means of x-ray diffractometer techniques as austenite.

Figure 2 shows the normal structure of S.A. 212 ferritic steel consisting of ferrite and pearlite. An increase in the ferritic grain size in the area close to the nickel plate as function of annealing time also was observed.

The normal structure of AISI 304 austenitic stainless steel consisting of austenitic grains is shown in Figure 8. Figure 10 shows the austenitic band between the nickel plate and the steel. Carbide precipitation is evident within the austenitic grains and also in the nickel. The dark lines within the grains are slip lines.

Micro-hardness tests were performed on both types of diffusion couples which were annealed for 4000 hours. The results of these tests are listed in Table IV. The width of the bands as a function of annealing time was also measured with the results shown in Table III. Figure 14 shows that the width of the bands increase exponentially as a function of annealing time.

V

DISCUSSION OF RESULTS

The results of this investigation are divided into two sections. The first deals with the reaction of nickel with S.A. 212 ferritic steel, and the second deals with that of nickel with AISI 304 austenitic stainless steels.

Nickel to S.A. 212

As a result of diffusion anneals between nickel and S.A. 212 ferritic steel various changes in the structure of the steel were observed. Annealing caused decarburization of the steel leaving only ferrite in the structure near the joint. The process of decarburization can be seen by comparing Figures 2 through 5. These figures show the structure of the steel after various annealing times up to 4000 hours. Decarburization is a result of carbon diffusion into the nickel plate.

An increase in the ferritic grain size close to the nickel plate is observed by comparing Figures 3 through 5. Recrystallization of the ferrite can take place above 1100^{o}F and as the amount of pearlite decreases through decarburization, grain growth should be expected. The elimination of pearlitic carbides removes the barrier to grain boundary movement and allows the ferritic grains to grow.

The original interface between the nickel plate and S.A. 212 ferritic steel lies within the dark band in Figures 3 through 5. Metallographic examinations indicated that the band extends more into the steel side of the diffusion couple. Voids were observed in the nickel plate. These voids are only observed after diffusion. Therefore, the amount of nickel diffusing into the ferritic steel may be assumed to be greater than that of iron diffusing into the nickel plate. The extension of the band into the ferritic steel is shown in Figure 7. Iron should have diffused into the nickel plate, but how far it has penetrated is not evident. The decarburization of ferrite indicates carbon diffusion in the direction of the nickel plate.

The martensitic structure of the band is obtained as a result of nickel diffusing into the ferritic steel. According to the constitution diagram[11] in Figure 1, the addition of nickel to S.A. 212 ferritic steel will cause martensite to form. The addition of nickel causes austenite to become stable at the annealing temperature and martensite was formed with air cooling.

The acicular appearance of the band seems to be less dense in the region of high nickel concentration. The cause of this density variation across the band is the concentration gradient of nickel, which gives a larger amount of retained austenite in the region of highest nickel concentration.[10] These two regions have different hardenability. The hardenability of low-carbon steels is fairly low. However, by a suitable alloy addition, such as nickel, the hardenability can be increased[12] by moving the C-curve to the right. Therefore, the region of high nickel concentration, which has a higher hardenability, may contain a large amount of retained austenite after cooling because the M_s and M_f lines are moved to lower temperatures by the addition of nickel.

To properly identify this acicular band as martensite, the diffusion couple annealed for 4000 hours was reheated to 700^{o}F for 16 hours. The appearance of this band after tempering is shown in Figure 7. The band, as a result of tempering, became darker as is expected when martensite is only partially tempered.

Micro-hardness measurements were made across the band as shown in Figure 6 and the values recorded in Table IV. Hardness values are a maximum in the martensitic band, and are greater on the nickel side of the band. A decrease in hardness occurred when indentations are made in either the ferritic steel or the nickel plate. In fact, the hardness of the band was four times that measured in either of the base metals. This high hardness again indicates that the structure within the band is martensite.

Measurements of the width of the band indicate that the width increases exponentially as a function of the diffusion anneal time. Figure 14 illustrates that the rate of increase in the width of the bands decreases as the anneal time increases. The rate of increase was greatest at the beginning of the anneal periods. This indicates that as the band increases in size the time required for the diffusing elements to move through the band increases. Thus longer diffusion times were required to produce the same increase in band width as occurred in the first few hours.

Nickel to AISI 304

The normal structure of AISI 304 austenitic stainless steel consists of austenite. After diffusion anneals, precipitation of carbides occurred within the grains but mostly along the grain boundaries. A distinct band was formed between nickel and the austenitic stainless steel. This band lies on the steel side of the interface as shown in Figures 9 through 11. The voids observed in the nickel indicates migration of nickel into the austenitic stainless steel.

As previously mentioned, Eckel[(10)] found a ferritic band between nickel and AISI 304 austenitic stainless steel. In his work, the specimen consisted of three layers; S.A. 212 ferritic steel, nickel, and AISI 304 austenitic stainless steel. The formation of this ferritic band was contributed to the diffusion of carbon from the ferritic steel through the nickel barrier into the austenitic stainless steel. The specimens used for the present study consisted only of two layers; nickel and austenitic stainless steel. The band formed between this couple was found not to be ferrite.

X-ray diffraction analysis of the band was made on the diffusion couple annealed for 4000 hours. Diffractometer techniques utilizing Cr-radiation was used for this study. The first three diffraction peaks (111), (200), and (220) of a face-centered cubic structure were identified. The x-ray data are given in Table V. As seen from this Table, the 2θ-values for the above peaks in the band were in all cases between the 2θ-values of the corresponding peaks of nickel and austenite. Because the structure of the band was found to be face-centered cubic, the band consists of austenite. No evidence of ferrite, which is a body-centered cubic, was found. The data given in Table V were obtained as a result of the incident x-ray beam parallel to the direction of diffusion. X-ray analysis also was made with the incidentbeam normal to the diffusion direction. The 2θ-values obtained in both cases were very close. The formation of austenite in this band is predictable because the diffusion of nickel stabilizes austenite in the steel. According to the constitution diagram[11] in Figure 1, Type 304 stainless steel becomes more austenitic (more stable in the austenitic form) with the addition of nickel.

To test the stability of this band, the couple annealed for 4000 hours was reheated to 1300°F for 30 minutes and then quenched in dry-ice and acetone in an effort to produce a martensitic structure within the band. Even with this treatment, there was no trace of martensite in the band. The temperature of the quenching medium was above the M_s-line and thus martensite could not form. The M_s-temperature for an 18-8 stainless steel is in the region of liquid nitrogen.[13] Figure 13 shows the structure of the band after reheating and quenching. Tempering the specimen at 600°F for 18 hours did not give any evidence of a break down in the structure which would occur with the tempering of martensite.

Elements migrating in this diffusion couple are nickel, iron, chromium, and carbon. Iron and carbon diffuse in the direction of the nickel plate. Nickel from the nickel plate diffuses toward the austenitic stainless steel. Chromium diffusion occurs two ways in the austenitic stainless steel. Carbide precipitation will occur in Type 304 stainless steel if the steel is either held in or cooled slowly through the range of 1200 to 1500°F.[1] The precipitation of carbides causes the migration of chromium from the surrounding austenitic regions and thus depleting these regions of chromium. The carbide precipitation both within the grain and along the grain boundaries is clearly shown in Figure 10. The presence of carbides on the nickel side of the interface indicates that the diffusion of chromium also occurred across the interface into the nickel. The existance of the nickel carbide, Ni_3C, is unlikely because of its instability.[6]

Micro-hardness indentations were made across the band as indicated in Figure 12, and the hardness values obtained are shown in Table IV. The greatest hardness was found at the interface between the band and nickel plate. This high hardness probably is the result of carbon dissolving to the solubility limit in nickel which produce a thin layer of hard material.[6] Hardness values in the nickel plate were found to be greater than in the austenitic stainless steel probably as a result of the presence of chromium carbides within the nickel.

The rate of increase in the width of the diffusion band was found to decrease with increasing annealing times. The exponential variation in the width of the band with time is shown in Figure 14. The width of the band in the nickel-AISI 304 couple initially was greater than that for the nickel-S.A. 212 couple for short annealing times. By comparing band width between the two couples in Figure 14, the rate of increase in the band in the nickel-AISI 304 couple increases slower than in the nickel-S.A. 212 couple as the annealing time increases. The greater increase in band width with annealing time in nickel-S.A. 212 couple suggests that iron and nickel diffuse faster in ferrite than in austenite. Guy[14] had published the values of diffusion constants of iron in alpha and gamma irons. Thus, iron has been found to diffuse faster in alpha iron than in gamma iron. The size of nickel atom is approximately same as that of iron. Thus, the diffusion rate of nickel in ferrite would probably be close to that of iron. Also, ferrite, which is body-centered cubic, has larger void space than a face-centered cubic structure such as austenite. Therefore, the nickel atom should be able to diffuse more easily in ferrite than in austenite.

Even though, there is a difference in the rate of increase in the width of the two bands, they will not approach the same thickness within a reasonable length of time. Extending the curves in Figure 14 gives an estimated annealing time of approximately 95 years (10^6 hours) at 1300°F to obtain the same thickness in the two bands.

VI

CONCLUSIONS

The following results were obtained in the metallographic examination of nickel-S.A. 212 and nickel-AISI 304 diffusion couples:

Nickel-S.A. 212 Couple

1. A martensitic band was formed between nickel and S.A. 212 ferritic steel.
2. The band extends more into the steel side of the interface than the nickel side.
3. Hardness values obtained were greatest within the band.
4. Width of the martensitic band increased exponentially with time of annealing.

Nickel-AISI 304 Couple

1. An austenitic band is formed between nickel and AISI 304 austenitic stainless steel.
2. No evidence of alpha iron structure in the band between nickel and AISI 304 austenitic stainless steel.
3. The band was found to be more on the steel side of the interface than on the nickel side.
4. Hardness values obtained were greatest at the nickel-band interface.
5. The width of the austenitic band increased exponentially with annealing time.
6. The rate of increase in the band width is greatest in the nickel-S.A. 212 couple than in the nickel-AISI 304 couple.
7. Chromium carbides were observed in the nickel plate near the interface between nickel and AISI 304 austenitic stainless steel.

VII

FUTURE WORK

Consideration in future work should be given to the use of markers to identify the original interface after diffusion. This method would be helpful in determining on which side of the interface the band occurs in the greatest amount. X-ray analysis, together with various heat treatments, should be used to identify the structure of the band produced at the interface of a diffusion couple.

VIII

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15. Tables for Bergsman's Micro-Hardness Tester.

IX

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TABLE I

Composition of Steels Investigated

Alloy	S.A. 212	AISI 304
% C	0.25	0.061
% Mn	0.74	0.56
% S	0.025	0.12
% P	0.013	0.016
% Si	0.20	0.49
% Cr	-----	18.97
% Ni	-----	10.74
% Mo	-----	0.18
% Cu	-----	0.07
% Pb	-----	0.0019
% Sn	-----	0.0125
% Co	-----	0.076
% Fe	Balance	Balance

TABLE II

Diffusion Anneal Times and Temperature

Couple	Bonding Time, Hours	Bonding Temp., °F
S.A. 212 to Nickel	50	1300
----	100	----
----	500	----
----	1000	----
----	2000	----
----	4000	----
AISI 304 to Nickel	50	----
----	100	----
----	500	----
----	1000	----
----	2000	----
----	4000	----

TABLE III

Widths of Band as a Function of Annealing Time

Joint	Width of Band in mm					
	50 hrs.	100 hrs.	500 hrs.	1000 hrs.	2000 hrs.	4000 hrs.
S.A. 212 to Nickel	0.0030	0.0045	0.0098	0.0140	0.0195	0.0271
AISI 304 to Nickel	0.0048	0.0070	0.0136	0.0191	0.0257	0.0360

TABLE IV

Micro-Hardness as a Function of Structure
in the Area of the Diffusion Bonded Interface

Bonded Material		Diamond Pyramid Hardness of Structure				
		Within Steel	Between Band and Steel	Within Band	Between Band and Steel	Within Nickel
Nickel and S.A. 212	Range of Hardness	45.3-84.1	109-169	318-343	169-318	34-148
	Average Hardness	69.3	137.6	330.4	280	71
Nickel and AISI 304	Range of Hardness	23.2-120	63.3-76.6	63.3-76.6	100-125	61.3-94.6
	Average Hardness	55.5	70.4	70.3	110.2	75.8

$$H_v = \frac{1854.4 \times P}{d^2} \qquad (15)$$

P = Applied Load in Grams

d = Average Length of Diagonal in Microns

TABLE V

X-Ray Diffraction Data for the
Nickel-AISI 304 Stainless Steel Diffusion Couple
Annealed at 1300°F for 4000 Hours

Material	2θ-Values (Degrees)		
	(111) Peak	(200) Peak	(220) Peak
Nickel	68.7	81.0	131.2
Band	67.1	79.3	129.2
Austenite	65.7	77.5	124.7

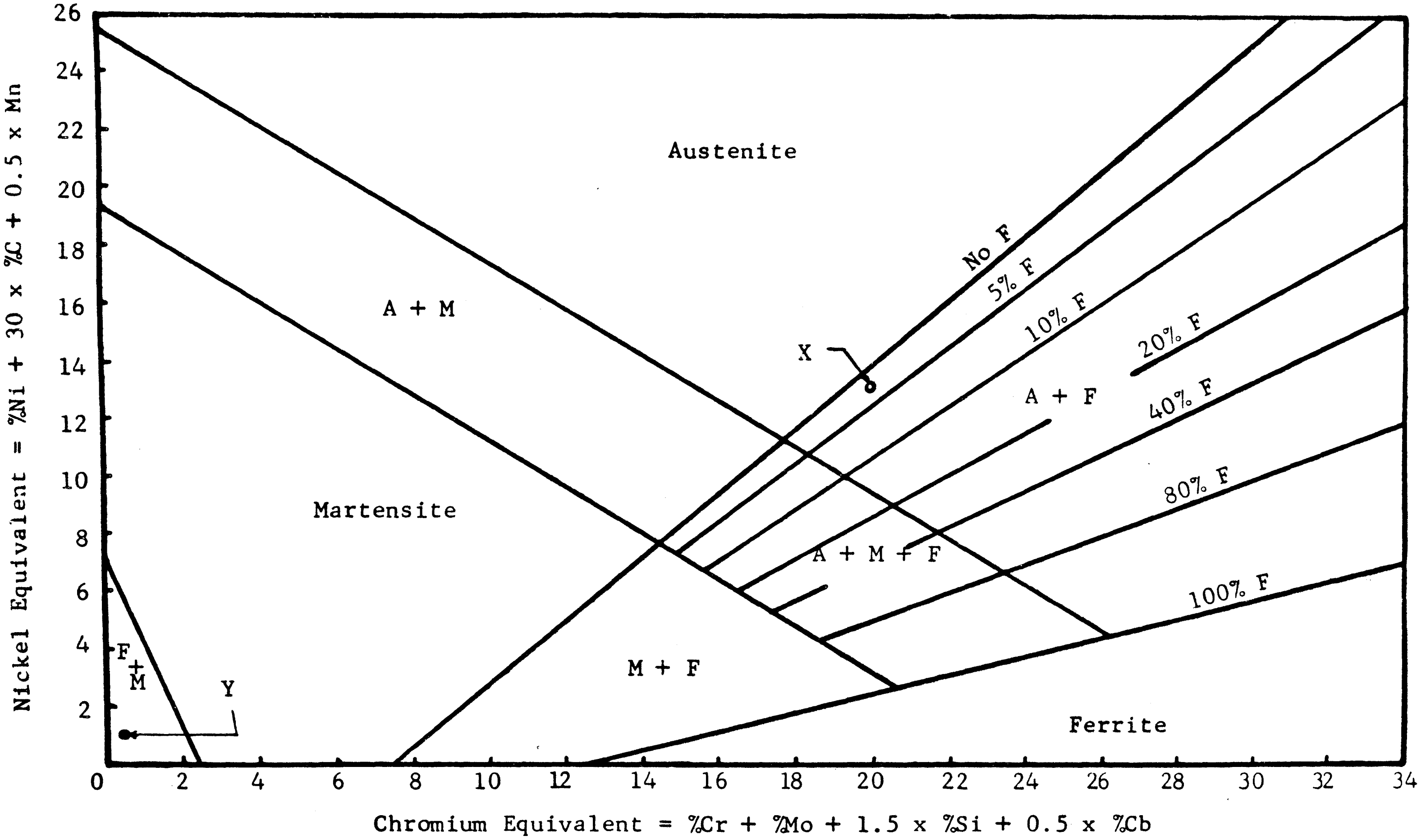

Figure 1. Constitution Diagram for Stainless Steel Showing Composition Equivalents on Structures

X = Equivalent Composition of Type 304 Stainless Steel
Y = Equivalent Composition of S.A. 212 Ferritic Steel

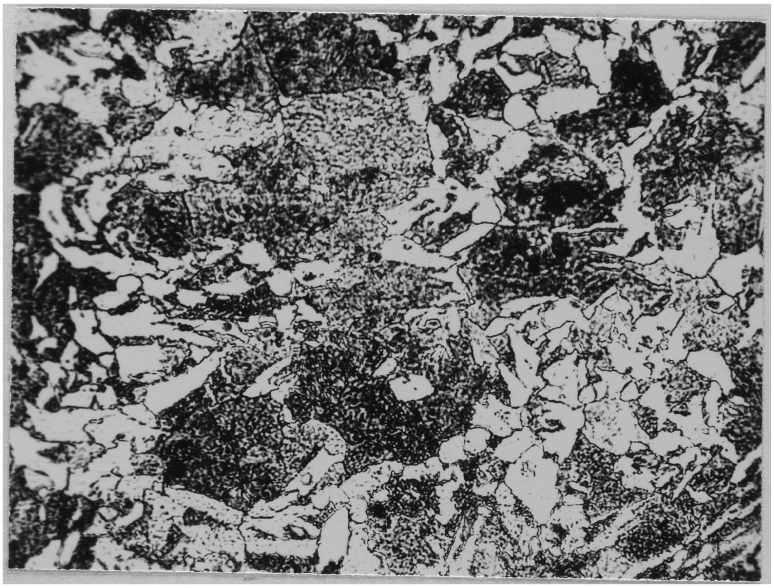

Figure 2. Normal Structure of S.A. 212 Ferritic Steel. 500X

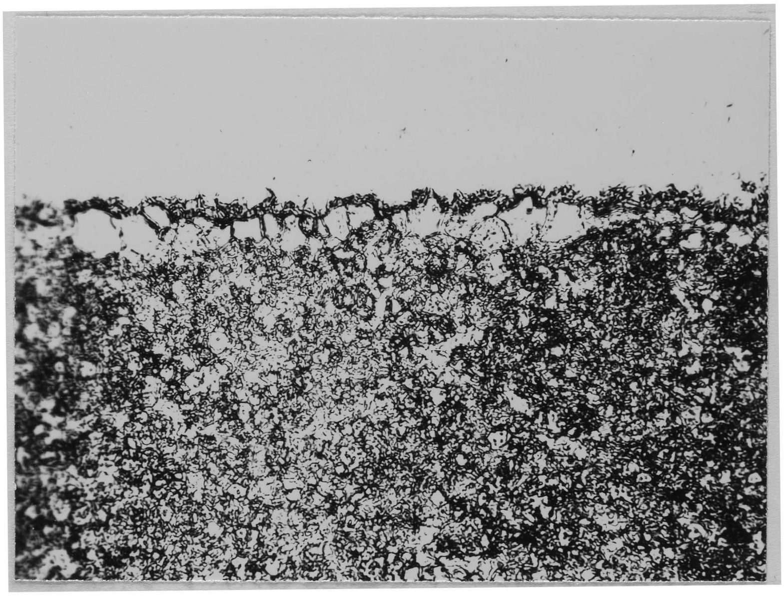

Figure 3. Nickel (top)-S.A. 212 (bottom) Diffusion Couple Exposed 100 Hours at 1300°F. 500X

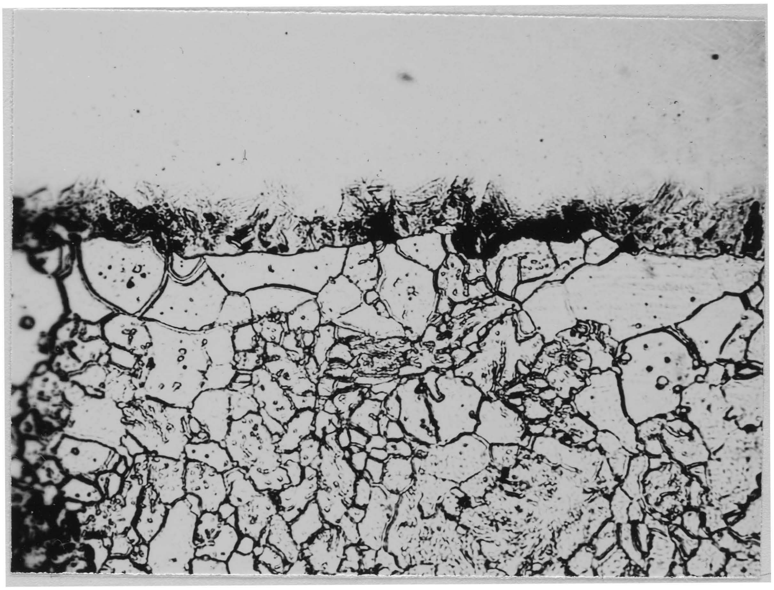

Figure 4. Nickel (top)-S.A. 212 (bottom) Diffusion Couple Exposed 1000 Hours at 1300^{o}F. 500X

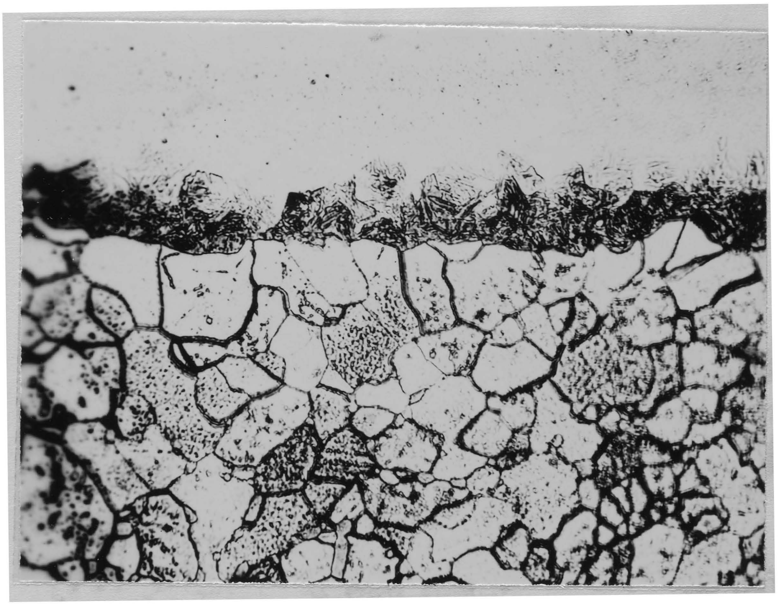

Figure 5. Nickel (top)-S.A. 212 (bottom) Diffusion Couple Exposed 4000 Hours at 1300°F. 500X

Figure 6. Nickel (top)-S.A. 212 (bottom) Diffusion Couple Exposed 4000 Hours at 1300 °F. 250X

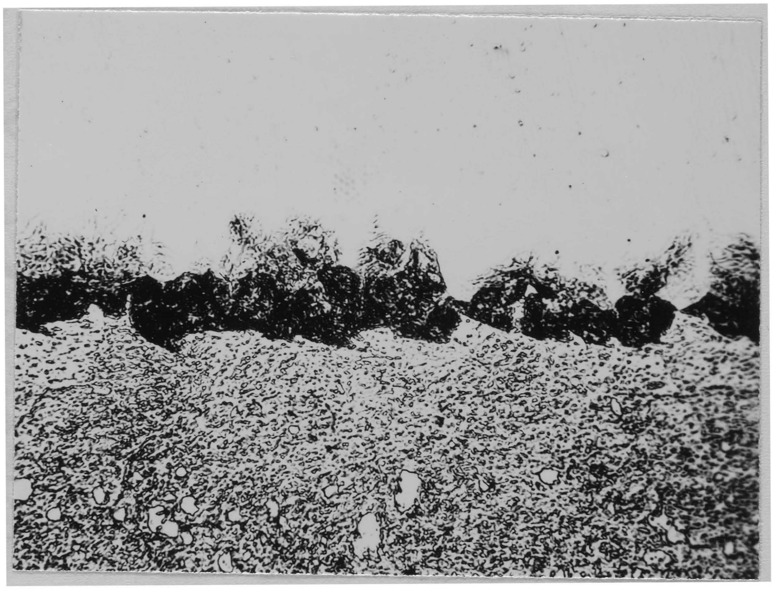

Figure 7. Nickel (top)-S.A. 212 (bottom) Diffusion Couple Exposed 4000 Hours at 1300°F, Reheated 16 Hours at 700°F and Water Quenched. 500X

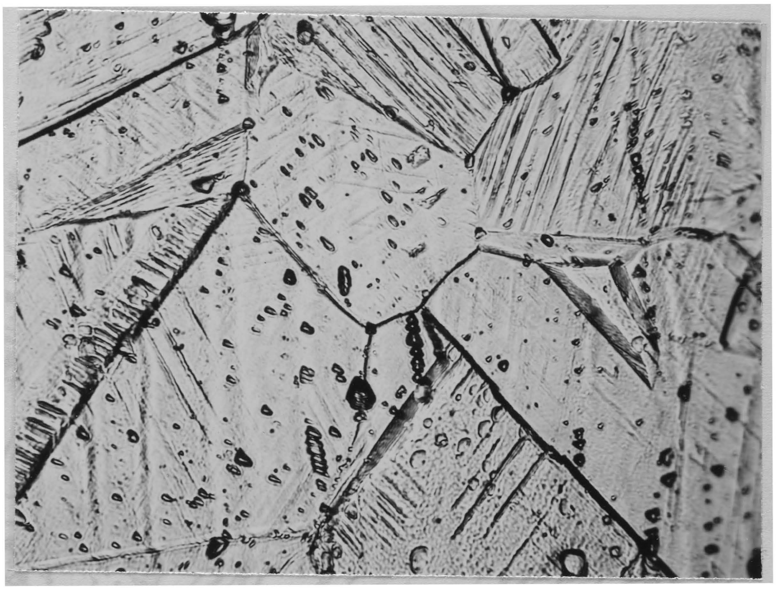

Figure 8. Microstructure of AISI 304 Stainless Steel in As-Received Condition. 500X

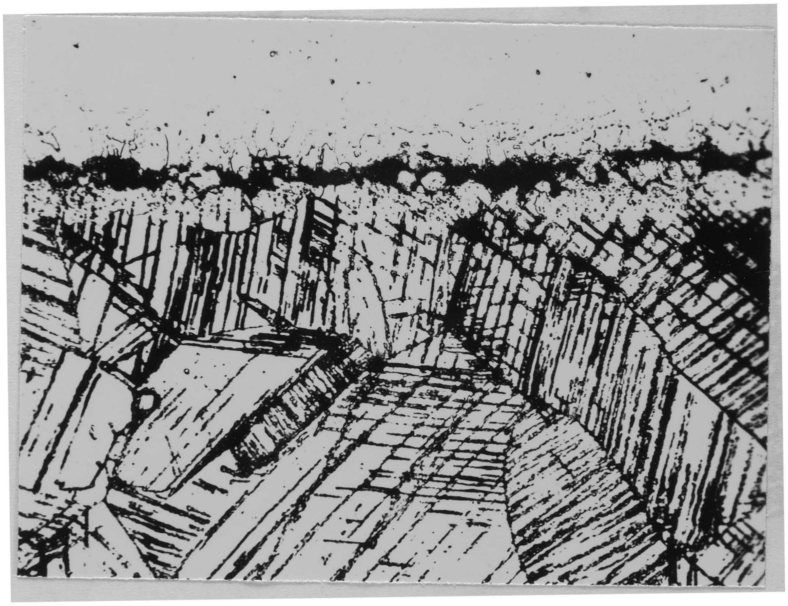

Figure 9. Nickel(top)-AISI 304 (bottom) Diffusion Couple Exposed 100 Hours at 1300°F. 500X

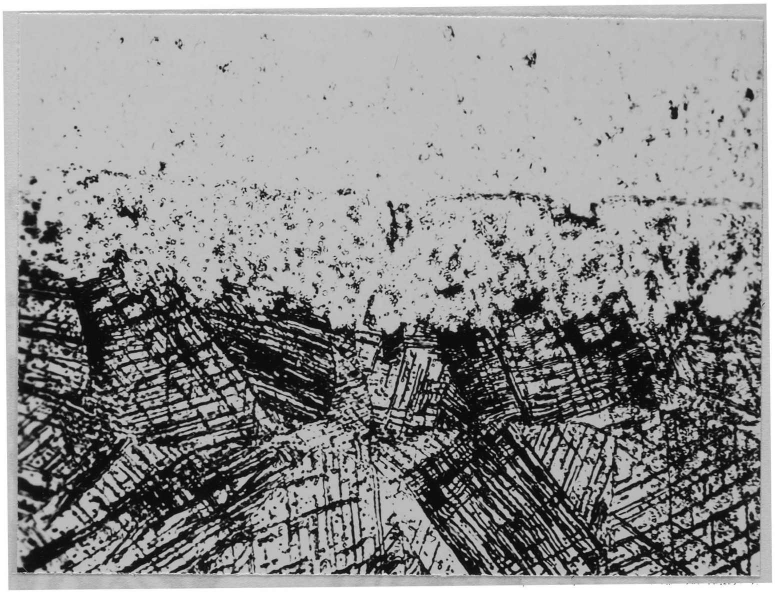

Figure 10. Nickel(top)-AISI 304 (bottom) Diffusion Couple Exposed 1000 Hours at 1300°F. 500X

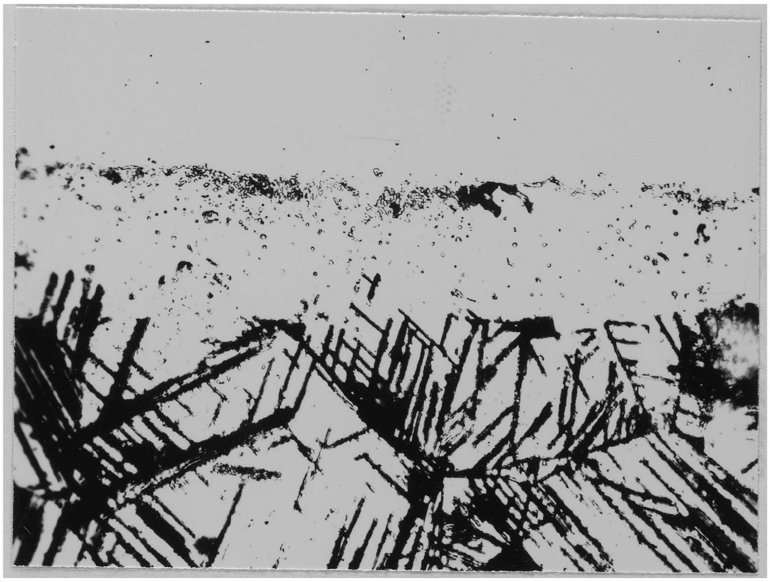

Figure 11. Nickel (top)-AISI 304 (bottom) Diffusion Couple Exposed 4000 Hours at 1300°F. 500X

Figure 12. Nickel (top)-AISI 304 (bottom) Diffusion Couple Exposed 4000 Hours at 1300°F. 250X

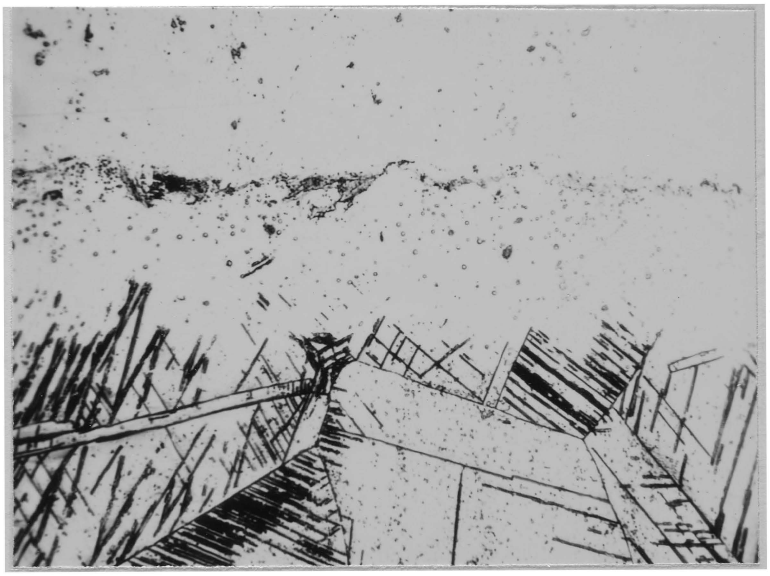

Figure 13. Nickel (top)-AISI 304 (bottom) Diffusion Couple Exposed 4000 Hours at 1300 ^{o}F, Reheated 30 Minutes and Quenched in Dry-Ice and Acetone. 500X

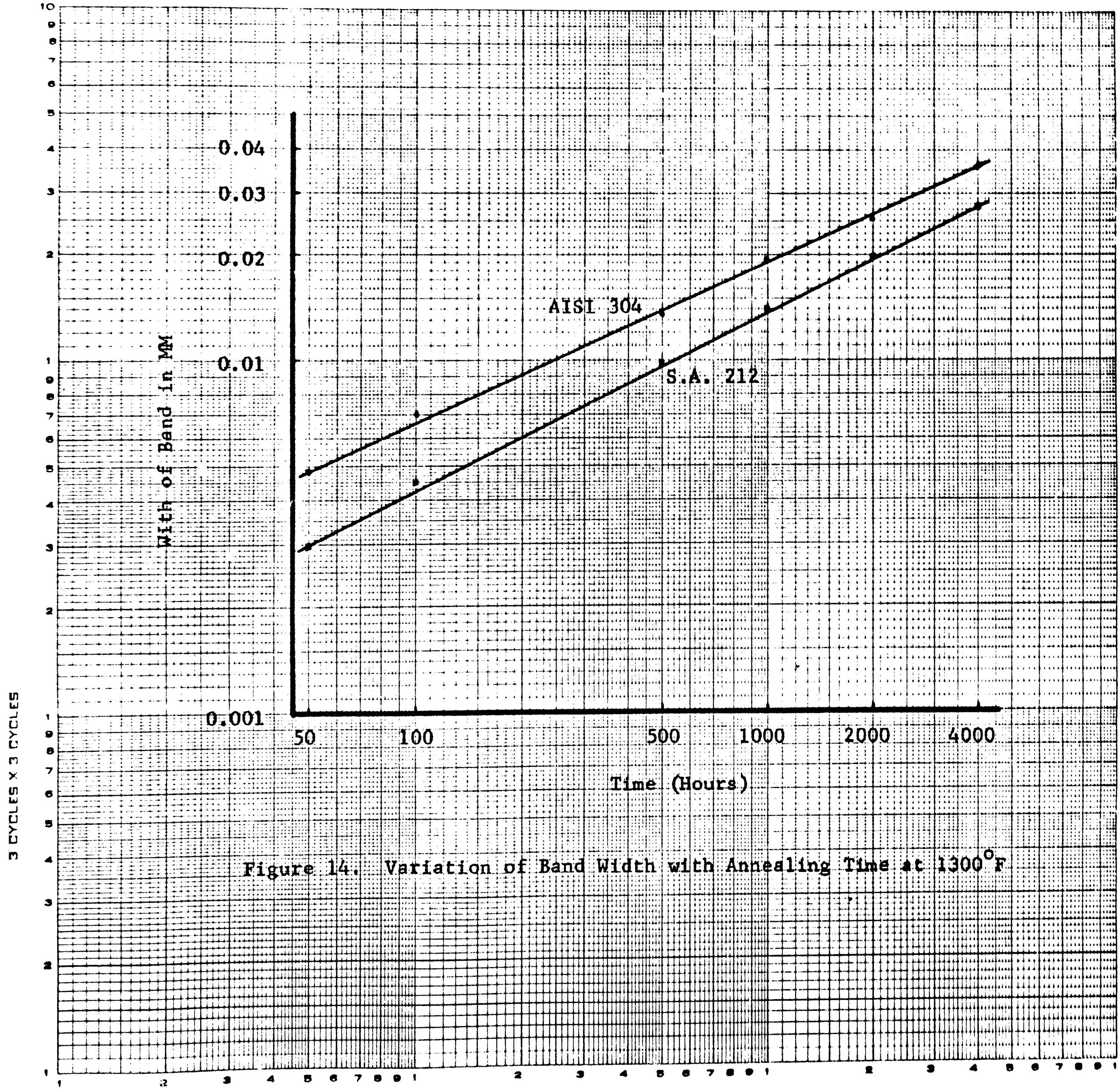

Figure 14. Variation of Band Width with Annealing Time at 1300°F

ABSTRACT

Diffusion couples between nickel and S.A. 212 ferritic steel and between nickel and AISI 304 austenitic stainless steel were studied to determine the effect of nickel on the structure of these steels after diffusion anneals at 1300 ^{o}F. Diffusion times varied from 50 to 4000 hours. The migration of nickel resulted in the formation of a martensitic band between nickel and S.A. 212 ferritic steel and an austenitic band between nickel and AISI 304 austenitic stainless steel. The width of the bands increased exponentially with the time of annealing. The band width increased faster in nickel-S.A. 212 couple than in nickel-AISI 304 couple. Hardness values were obtained within the band of both diffusion couples and varied across the band. Generally, the hardness was greatest in the band. In the nickel-AISI 304 diffusion couple, chromium carbides were observed in the nickel plate after diffusion.