

Corrosion Resistance of Stainless Steel Weldments

References totalling 113 are cited in discussion relating weldment corrosion to metallurgical, chemical and physical changes introduced during welding

BY K. E. PINNOW AND A. MOSKOWITZ

Introduction

Stainless steels provide an outstanding combination of engineering properties, including excellent weldability. Selection of these steels for use in corrosive environments is generally based primarily on their resistance to corrosion in the annealed condition. Improper welding practices, or poor choice of steel, can raise the corrosion rate at or near the weld in certain media to levels considerably above that for the annealed condition. The causes for such increased attack are not always well understood. Present knowledge on changes in corrosion resistance that may be associated with the welding of stainless steels has therefore been reviewed to indicate the problems and to elucidate areas most needing further research.

Corrosion of stainless weldments may occur in the weld metal, in a heat-affected zone of the base metal, or both. Various possible regions of corrosion are illustrated in Fig. 1. In general, weldment corrosion can be related to the metallurgical (structural), chemical, and physical changes introduced during welding.

Metallurgical Factors

Carbide Precipitation—Austenitic Stainless

Weldments in austenitic stainless steels may show susceptibility to intergranular attack in certain media.¹⁻¹⁰ In the unstabilized steels such as T304 and T316, such attack occurs in a narrow band parallel to and at some distance away from the weld, and is referred to as weld decay. In general, the attack is associated with the precipitation of chromium carbides at the austenite grain boundaries. The location of the attack corresponds to

regions that were heated during welding to temperatures from about 1100 to 1500° F. At these temperatures, carbide precipitation is most rapid.

Many environments do not produce intergranular attack of the austenitic stainless steels, even when the steels contain heavy carbide precipitation. Information on environments causing intergranular attack in austenitic stainless weldments is given in several publications.¹¹⁻¹⁴ Attempts have been made to generalize on the types of solutions that would cause attack based on oxidation-reduction potentials or other characteristics,^{15, 16} but the picture is not completely resolved. More work could be done on this, and on relating solution characteristics to the features in the heat-affected zone that lower corrosion resistance.

The most widely accepted theory of intergranular corrosion in welded austenitic stainless steels involves the formation of a chromium depleted zone at the grain boundaries due to chromium carbide precipitation.¹⁷⁻¹⁹ The precipitated carbides themselves are not ordinarily attacked. However, since they contain more chromium than the matrix, their formation requires diffusion of chromium from the surrounding areas; these areas are lowered in chromium and become less resistant to attack in certain media.

Although the theory of chromium depletion is generally consistent with the experimentally observed phenomena, there are questions about its validity and alternate mechanisms have been proposed.^{10, 20, 21} There is very little direct evidence of chromium depletion, for example, and it is difficult to account for the very short heating times capable of producing sensitization. Furthermore, there is experimental evidence indicating that the dependence of the susceptibility to intergranular corrosion on the time and temperature of heating relates to the morphology of the precipitated grain boundary carbide.^{22, 23}

Most of these objections to the chromium depletion theory have been countered in detail.²⁴ Moreover, a recent study of the diffusivity of carbon and chromium in an 18-8 steel has provided a model of chromium depletion which can be used to accurately calculate the time-temperature-sensitivity diagram for a steel with any chromium and carbon content.²⁵ The matter is still of theoretical interest, and it is possible that further microprobe and/or polarization studies might provide valuable results.

Susceptibility to weld decay can be effectively overcome by full annealing and rapidly cooling the weldment. Unfortunately, this is not always possible with massive components or where there is danger of distortion. Alternate means involve the use of austenitic stainless steel with very low carbon contents (T304L, T316L, etc.) or with sufficient titanium or columbium to "stabilize" the steel by forming relatively insoluble carbides (T321, T347, etc.). However, other properties of specific alloys may preclude such compositional changes. Stainless steels with duplex austenite-ferrite structure are also reported to be helpful.^{6, 10}

Although the austenitic stainless steels containing titanium or columbium are resistant to weld decay, they may become susceptible after welding to intergranular attack in a zone immediately adjacent to the weld. Apparently two types of corrosion can be encountered. The better known one, which can occur in a number of environments, is called "knife line attack". The other type of attack, which is specific to nitric acid and probably other highly oxidizing media, is best referred to as "fissure attack". In general, "fissure attack" only occurs when the carbon content exceeds about 0.05%. Both types of corrosion apparently relate to dissolving of the titanium or columbium carbides during welding and, consequently, only

K. E. PINNOW is Senior Research Metallurgist, Crucible Materials Research Center, Crucible Inc., Cole Industries, Pittsburgh, Pa., and A. MOSKOWITZ is Director—Technical Services, Crucible Stainless Steel Division, Colt Industries, Midland, Pa.

occur in zones adjacent to the weld metal where very high temperatures (above 1800° F) are encountered in the welding operation.

“Knife line attack” is caused by the dissolving of titanium or columbium carbides during welding and the subsequent precipitation of chromium carbides at the grain boundaries.^{8, 26} Such precipitation does not normally occur in the initial cooling of the weld, but only during reheating to the vicinity of 1200° F as in multipass welding, stress relief, or in service at elevated temperatures.

It has been reported that knife line attack can be prevented by a “stabilization” heat treatment at about 1600° F after welding.²⁷⁻²⁹ This treatment is designed to precipitate titanium (or columbium) carbides, thereby tying up the carbon and preventing precipitation of chromium carbides on subsequent exposure to sensitizing temperatures. However, some studies have indicated that such a stabilization treatment may sometimes be ineffective or even detrimental.¹¹

The mechanism of “fissure attack”, which is also called “knife line attack” by some investigators, has received considerable study.³⁰⁻³⁶ Basically, it appears to involve the preferential attack in nitric acid of titanium or columbium carbides, and possibly sulfides, that form in the grain boundaries during welding. The formation of these carbides is enhanced by delta ferrite which therefore increases the sensitivity of a steel to this type of corrosion. Fissure attack is unlike ordinary weld decay in that it does not occur in the absence of strong carbide forming elements nor can it be remedied by ordinary annealing treatments.¹⁰

Carbide Precipitation—Ferritic Stainless

As with the austenitic stainless steels, welding can increase the susceptibility of the ferritic stainless steels to intergranular attack.³⁷⁻⁴² Attack can be produced by a wider range of conditions than for the austenitic steels, and has been reported in media as mild as tap water.⁴¹ In the ferritic stainless steels such as T430 and T446, the attack is immediately adjacent to the weld and in some cases includes the weld metal. The reason for this is that temperatures above 1700° F are involved in producing the sensitized condition. This form of weld zone attack has been reported to occur only in ferritic stainless steels containing more than about 15% chromium. Steels of lower chromium content such as T410, T416, and T409 do not appear susceptible.⁴¹

Susceptibility to intergranular attack of the welded ferritic stainless

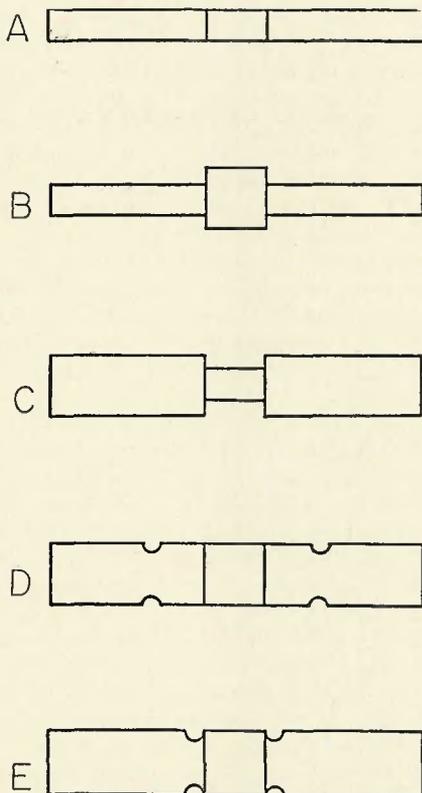


Fig. 1—Regions of possible corrosion of stainless weldments: A—general; B—base metal; C—weld metal; D—heat-affected zone (austenitic stainless); E—knife line (stabilized austenitic stainless), heat-affected zone (ferritic stainless)

steels can be effectively eliminated by post-weld-annealing at 1200 to 1500° F. The addition of titanium or colum-

bium in sufficient amounts will prevent attack in acidified copper sulfate, but not in more highly oxidizing environments such as boiling 65% nitric acid.^{38, 42, 43} Lowering both the carbon and nitrogen contents to extremely low levels (on the order of 0.003%) appears to provide immunity to attack in both of these media.⁴⁰⁻⁴⁴ The effects of carbon and nitrogen levels are shown in Table 1.

Several mechanisms have been advanced to account for the intergranular corrosion of the ferritic stainless steels. Earlier explanations relate corrosion to the formation of a duplex austenite-ferrite structure at elevated temperature and the subsequent attack of the martensite or easily corroded carbides formed from the austenite on cooling.^{37, 45} Subsequent work has shown, however, that austenite formation is not a necessary condition. Susceptibility to corrosion appears to relate to the dissolving of carbides or nitrides and their subsequent precipitation in the grain boundaries on cooling.

One proposed mechanism is that these precipitates strain the matrix adjacent to the precipitate and thereby make the grain boundary area susceptible to attack in corrosive solutions.³⁸ Annealing at 1200 to 1500° F supposedly relieves the stresses and corrosion resistance is recovered. Another proposed mechanism is that intergranular corrosion is generally caused by the depletion of chromium in areas adjacent to precipitates of

Table 1—Corrosion of 17% Chromium Stainless Steels With Various Carbon and Nitrogen Contents in Boiling 65% Nitric Acid⁴²

Alloy	Carbon, %	Nitrogen, %	Corrosion rate, mdd, in successive 48-hr periods after 1 hr of heat treatment at the indicated temperature			
			1450° F	1700° F	1900° F	2100° F
270A	0.0021	0.0095	137	127	106	164
			161	159	160	251
			172	189	144	319
			181	230	171	419
			182	254	159	479
			133	226		103
270B	0.0025	0.022	162	520		368
			173	924		848
			174	1390		1121
			180	1658		1365
			157		194	95
			186		411	226
270D	0.0044	0.057	186		596	321
			200		783	482
			200		901	660
			116	366	96	
			136	392	572	
			132	852	2712	
271A	0.012	0.0089	128	1179	3232	
			118	1329	2475	
			130	195	107	
			154	420	624	
			152	696	1827	
			162	861	2545	
271D	0.061	0.0071	137	925	2766	

chromium carbide or chromium nitride.⁴² In the alloys containing titanium or columbium, the carbide precipitates themselves may be attacked in highly oxidizing media. In this respect, titanium carbides appear more susceptible to attack than columbium carbides.⁴³ Of the two proposed mechanisms, the latter can account for the difference in behavior noted for the titanium or columbium stabilized ferritic steels in acidified copper sulfate and in boiling nitric acid media.

Thus, it would seem that the basic mechanisms responsible for intergranular attack in the ferritic stainless steels could be similar to those responsible for weld decay and "fissure" or "knife line" attack in the austenitic stainless steels. Observed differences in time-temperature conditions leading to such attack can be reconciled in terms of the lesser solubilities and higher diffusion rates of carbon and nitrogen in ferrite as compared to austenite.⁴² Additional study of the chromium depletion hypothesis is needed.

The ferritic stainless steels may grow in industrial importance. They have not been used as widely as the austenitic stainless steels because of such factors as poor corrosion resistance after welding, and low toughness. Recent technological breakthroughs suggest, however, that it may be commercially feasible to melt these steels to extremely low carbon and nitrogen contents.⁴⁶ The weldability, toughness, and corrosion resistance of such steels are reported to be excellent. Furthermore, these new ferritic stainless steels are probably not susceptible to stress-corrosion cracking.⁴⁷ Studies are needed on the corrosion characteristics of weldments in these new materials.

Delta Ferrite

To minimize hot cracking, the compositions of austenitic stainless weldments are generally balanced to form a small percentage of delta ferrite in the weld metal. Optimum crack resistance is reportedly achieved with a ferrite content from about 5 to 10%.⁴⁸ Also, a small amount of ferrite in weld overlay deposits may increase resistance to stress corrosion cracking.

Published information indicates that the effects of delta ferrite on corrosion resistance vary with steel composition. In austenitic steels and weld filler metals without molybdenum, delta ferrite itself does not appear to reduce corrosion resistance in environments in which these steels are normally resistant.⁴⁹⁻⁵¹ However, during the slow cooling encountered in heavy weldments or during thermal stress

relieving, chromium carbide readily and preferentially precipitates in the ferrite-austenite grain boundaries. Such precipitation is generally not harmful when the amount of ferrite is small; in this case, the ferrite may actually be beneficial in preventing a continuous carbide network.^{20,52} However, when sufficient ferrite is present (above 10%) to form a continuous network, intergranular corrosion can result.⁵¹

Preferential attack on the delta ferrite has been reported in weldments made from the molybdenum-bearing austenitic stainless steels such as T316 and T316L.⁵³⁻⁵⁶ Thus, there are specifications which severely limit permissible ferrite in both the base and weld metals, as for urea plant service.⁵⁶⁻⁵⁸ Attack of the ferrite in these steels has been related to the fact that they are generally used in more corrosive media than are the molybdenum-free steels. However, it is not clear whether attack is actually on the ferrite, itself. Several studies indicate that corrosion associated with the ferrite in these steels relates more to carbide precipitation or to the formation of sigma phase from the ferrite.^{51, 56}

The control of ferrite content in welding can be a difficult matter. Aside from the composition of the weld and parent metals, the welding technique is important.⁵⁹ The situation is further complicated by the difficulty in reliably measuring ferrite content in weldments.⁶⁰

The corrosion problems associated with ferrite in T316 and T316L can reportedly be overcome by postweld annealing or by other heat treatment.⁵⁴ One particular area of interest is welded tubing, wherein "full-finished" product is cold worked and annealed after welding to eliminate ferrite and possibly other segregation effects. Heat treatments are often impractical in the field, and in some applications it might be preferable to use fully austenitic weld filler metals. Such filler metals increase the likelihood of hot cracking, but crack-resistant fully austenitic weld filler metals are being developed.^{61, 62} Increased knowledge of environments that cause ferrite attack would be useful to indicate applications for which fully austenitic weld filler metals should be considered.

Sigma Phase

Under some conditions, the welding or heat treatment of certain austenitic stainless steels such as T316, T316L and T321 can produce sigma phase at the austenite grain boundaries. Sigma phase is an intermetallic compound consisting primarily of iron and chromium, although it can be enriched with other ferrite forming elements

such as silicon, molybdenum, and titanium. Sigma phase has been reported to produce intergranular attack in nitric acid and in hot strong (40 to 80%) sulfuric acid solutions, but does not appear to produce corrosion in other media.^{6, 12, 63-68} It appears that sigma is detrimental primarily when present below the level of detectability ("submicroscopic sigma").

Sigma phase can form more readily from delta ferrite than from austenite. The ferrite used to minimize hot cracking in austenitic stainless can thus introduce sigma phase. Sigma readily forms from the ferrite in the high chromium and molybdenum-containing austenitic stainless steels such as T316 and T309.^{56, 69} However, it does not seem to form from the ferrite in lower chromium or molybdenum-free steels such as T304 at the temperatures and times encountered in welding or in stress relief.⁵¹ No detailed information was found concerning possible sigma phase precipitation in the welding of ferritic stainless steels with high chromium or molybdenum contents, although the possibility of intergranular attack associated with such precipitation has been considered.¹⁰ Studies on high-purity low interstitial ferritic stainless steels would be of interest.

The mechanism of the intergranular attack produced by sigma phase formation is not well understood and merits further study. Factors to be explained include the detrimental effect of agglomeration may relate to not in the ferric sulfate or Strauss tests, and the general elimination of detrimental effects when sigma is agglomerated by heat treatment and thereby visibly present. It would appear that either a chromium depletion mechanism or attack on the sigma itself might be involved.

A chromium depletion mechanism has been suggested in several publications.^{51, 65} The extent of depletion should be less than with carbide precipitation, because the chromium content of sigma is lower than that of chromium carbide. This could explain why corrosion occurs in the Huey test, but not in the other less severe tests and environments. The beneficial effect of agglomeration may relate to chromium equalization by diffusion during the longer time at temperature.

With regard to possible attack on the sigma itself, sigma has a high chromium content and so should resist corrosion in many environments. However, it is possible that it could be attacked in highly oxidizing environments with the formation of chromate. This could explain the different effects in the various tests. The benefi-

cial effect of agglomeration could result from its providing discrete sigma particles in place of a continuous grain boundary network.

Stress relief could also be involved in the beneficial effects of agglomeration. It has been proposed that stresses associated with precipitation of sigma in ferrite might be responsible for "knife line attack" in the titanium stabilized austenitic steels.⁷⁰

Chemical Factors

Chemical changes occurring in the welding of stainless steels can affect corrosion resistance. The changes relate primarily to dilution or alloying produced by dissimilar weld filler and base materials, and to reactions with the slags or atmospheres used in welding. There can also be segregation effects in the weld metal.^{71,72} Improper dilution has caused corrosion of stainless weld overlays. In such cases, composition heterogeneity and insufficient alloy content seem to be the principal causes of attack.^{73,74} Weld dilution would also seem to be an important factor affecting the corrosion resistance of welds in stainless clad materials.^{75,76} In both cases, corrosion is related to welding procedure and the choice of electrode material, and can probably be avoided by improved welding techniques.

The atmospheres present during welding can be the source of several changes in composition. Carburization by carbon dioxide in certain welding gases or by carbon pick-up from covered electrodes is detrimental, although such carburization has appeared hazardous only in multipass weldments or in weldments which are thermally stress-relieved after welding.^{77,79} It might be more of a problem in ultra-pure ferritic steels; research on this would be helpful. In these steels, very low carbon (and nitrogen) contents are essential for weldment corrosion resistance.

Oxidation can cause loss of chromium and of stabilizing elements such as titanium from the weld metal.⁸⁰ In addition, it can produce surface chromium depletion in the heat-affected zone.⁸¹ Descaling alone may not be sufficient to prevent corrosion in such cases inasmuch as the chromium-depleted base material also needs to be removed. Chromium depletion produced during welding would be particularly significant with the ferritic stainless steels of low chromium content.⁸²

Nitrogen pick-up could conceivably produce corrosion in the heat-affected zone of ferritic stainless steels where it is known to increase the susceptibility to intergranular attack. Investigations

with the ultra-pure ferritic stainless steels would be of particular interest. Nitrogen pick-up in austenitic stainless weldments does not appear particularly harmful, aside from the risk of porosity. This is because of the relatively high solubility of nitrogen in austenite. However, nitrogen can combine with stabilizing elements such as titanium and thereby reduce their effectiveness.

Slags from electrode coatings used in welding can also be significant sources of weld corrosion. Incomplete slag removal after welding is reported to cause attack of nickel base materials and of the molybdenum bearing austenitic stainless steels during high temperature service and in heat treatment.⁸³⁻⁸⁵ Fluoride contamination from welding slags may also cause intergranular attack.⁸⁶

In considering chemical factors, it should be noted that there can also be galvanic interactions between adjacent metals of unlike composition.^{87,88} Such galvanic effects would tend to be detrimental to the less corrosion resistant material and protective to the more resistant one. For example, the use of an improperly chosen weld filler metal with less corrosion resistance than the base metal could give rise to significant galvanic corrosion in some environments. Compositional differences could also arise through dilution, segregation, reactions with environment, etc.

Physical Factors

Physical factors such as weld geometry and residual stress can significantly affect the corrosion resistance of stainless weldments. Weld geometry is controlled by the method of welding, although technique and workmanship are important variables. Undercutting, mismatch, and other related defects can cause severe crevice corrosion, even though the welds are otherwise sound and free of undesirable metallurgical effects.⁸⁹ Weld reinforcement (excess weld metal) may also produce crevice corrosion, and may otherwise contribute to corrosion by trapping or retaining surface corrodents. For this reason, weld reinforcement is almost always removed from the process side of tanks and other chemical apparatus. Removal of weld reinforcement can be costly, however, and information on when it is necessary would be useful.

Residual stresses introduced during welding can increase the susceptibility of austenitic stainless weldments to stress-corrosion cracking.⁹⁰ Such cracking of welded apparatus has been considered in detail.⁹¹ Corrective measures generally involve the use of materials more resistant to stress cor-

rosion, changes in operating conditions, or elimination of unfavorable tensile stresses. Austenitic stainless steels with higher resistance to stress corrosion cracking have been developed, but are generally expensive because of high nickel content.⁹²⁻⁹⁵ With certain of these alloys, it is also difficult to avoid carbide precipitation during welding.

Unfavorable residual tensile stresses can be reduced either mechanically, as by shot peening, or by thermal stress relief. Studies have been reported on the use of vibrational methods to relieve stresses; the effectiveness of such methods is not fully resolved.⁹⁶⁻⁹⁸ Heat treatment of the austenitic stainless steels should be conducted carefully so as to avoid adverse effects on mechanical properties and corrosion resistance by possible carbide or sigma phase precipitation. Stress relieving of the stainless steels has been reviewed extensively.^{91,99-102}

Ferritic stainless steels are generally immune to stress corrosion cracking, although they may become susceptible at certain critical nickel or copper contents.¹⁰³ The new high-purity ferritic stainless steels now being commercially developed may provide a practical solution.

Test Methods

Numerous tests have been proposed for evaluating the susceptibility of stainless steels to intergranular attack.^{10,53,104-107} Corrosion of stainless weldments is most often intergranular in nature. For this reason these tests together with appropriate specimens are often used for quality control or to predict whether welding will increase susceptibility to corrosion in service. Most widely used are the boiling nitric acid (Huey), the acidified copper sulfate (Strauss or Hadfield), the ferric sulfate-sulfuric acid, the nitric-hydrofluoric acid, and the oxalic acid etch tests.

Some of these tests are sensitive to other factors in the steels as well as to intergranular carbide precipitation. For example, sigma may lower the corrosion resistance of T316 in boiling nitric acid, but not in other environments. Thus, the Huey test is not appropriate for determining whether welded T316 will be satisfactory in general field service. The ASTM has therefore proposed a test sequence based on steel compositions.¹⁰⁸ Electrochemical tests have also been used, but as indicated earlier there are questions concerning their validity as used thus far.

Corrosion test results in any one chemical environment may not correlate with those in other environments.

For example, the effects of certain compositional or structural features can even be, in effect, unique to one environment. Thus consideration must be given to how valid results in any one test are in relation to a variety of service environments.^{11,13,109,110}

To simulate the metallurgical effects produced by welding, specimens for accelerated laboratory testing are often heated isothermally for short periods of time at a temperature in the 1100-1300° F region. This procedure is based on the assumption that the resistance to isothermal sensitization is an accurate indication of the tendency for carbide precipitation during welding. Such treatments in terms of actual weldment behavior are generally overly severe as illustrated in Table 2, but nevertheless appear useful for quality control.^{7,11,110-112} Welded samples have also been used, but it is difficult to rate their corrosion resistance quantitatively.

Data have been developed indicating the maximum heating times in the sensitization range for steels of different compositions to remain resistant to intergranular corrosion.^{10,111} Such information, when combined with data on the exposure times to certain temperatures in the heat-affected zone of weld joints, could be useful for steel selection. This quantitative approach should receive greater study.

Intergranular corrosion in the accelerated laboratory tests can be assessed in various ways. Bend tests, "ring" tests, and microscopic tests are generally employed to provide qualitative data. Weight loss, electrical resistance, and eddy current measurements provide quantitative information. All these approaches are satisfactory with laboratory sensitized samples but are more difficult to apply to actual weldments. Electrochemical means for evaluating the corrosion of welded joints are being studied.^{88,113}

Conclusion

A comprehensive review of present published information on corrosion of stainless weldments indicates both that much has been done and that there are still important areas that could usefully be investigated. Most of the problems that can arise, and the procedures to avoid them, are reasonably well understood. Among the metallurgical factors, the most extensively documented area is that of sensitization of austenitic stainless steel (carbide precipitation); less has been done on sensitization of the ferritic stainless steels. Information on ferrite and sigma is not particularly thorough. On chemical and physical factors, there is much applicable information de-

Table 2—Comparative Severity of Welding and Heat Treatment in Causing Intergranular Corrosion of Various Stainless Steels¹¹

Type	Number of racks showing intergranular attack ^a	
	Welded	Heat treated ^b
316L	0	11
316	1	15
317	6	22
318	1	21
302	15	19
304	1	10
304L	0	5
321	6	12
347	1	13

^a Racks (24 specimens) exposed to a number of actual service environments for times ranging from 30 to 1600 days.

^b Specimens heat treated for 1 to 4 hr at 1100 to 1250° F.

veloped in work not specifically aimed at welding. The problem here would seem to be more in "translating" available information rather than in performing new research.

In regard to areas for investigation, work such as the following should be worthwhile:

1. Perform research aimed at developing a consistent overall "theory of sensitization" for austenitic stainless steels. Local changes in chemistry and structure in the steel weldment should be related to the corrosive characteristics of environments that produce intergranular attack. A combination of microstructural, microprobe, and electrochemical approaches might be applied. Quantification of carbide precipitation in terms of alloy composition and thermal conditions would be useful. Aside from surprising new results that might develop from such work, the findings should permit generalization on environmental factors, and lead to the development of new and improved testing procedures.

2. Attempt to determine the mechanism of intergranular attack in the heat-affected zone of ferritic stainless steels. Explore the extent of immunity of ferritic steels with extremely low carbon and nitrogen contents and determine the effects of increasing the level of these elements.

3. Perform studies to clarify the role of delta ferrite in relation to weldment corrosion. Determine the composition and electrochemical characteristics of the ferrite compared to those of the austenite, including work with different austenitic compositions. Study the effects of variations in the quantity and morphology of the ferrite. Determine whether corrosion relates to the ferrite itself, to carbide precipitation from the ferrite, or to sigma. Develop information aimed at formulating generalizations

relating to the nature of corrosive environments.

4. Study the relationship of compositional changes in welding to corrosion resistance, particularly with relatively low-alloy materials and with high-purity ferritic steels. With the low-alloy steels, modest losses in chromium as from oxidation could be important. With the high-purity ferritics, weldment corrosion resistance might be seriously affected if carbon or nitrogen pick-up occurred in certain types of welding.

5. Perform research on the origin and magnitude of residual stresses associated with various methods and techniques of welding. This work would involve the development and application of methods for accurate stress determination. Study the effectiveness of possible methods to relieve stresses, with the aim of developing methods that do not involve other complications such as carbide precipitation. Attempt to quantify the relationship of residual stress level to susceptibility to cracking in service.

6. Develop standard methods for testing weldment corrosion resistance that could be used for alloy development and for determining suitability of any alloy in service environments. Work on methods involving both isothermal treatments and actual welding. With welding, determine how the welding should be done and how test results should be quantified. Determine whether a limited number of test solutions could represent a wide range of service environments. The previously suggested quantification of carbide precipitation, in association with thermal studies in welding, would permit interpretation of test results in relation to service conditions.

References

1. Bull, H., and Johnson, L. "Welding of Stainless Steels" *Ind. Gases*, 9(1928) 8-20.
2. Matthews, J. A., "Cause and Cure of Intergranular Corrosion in Austenitic Steels." *J. Am. Weld. Soc.*, 11 (1932) 21-27.
3. Pfeil, L. B., and Jones, D. G., "A Contribution to the Study of the Properties of the Austenitic Steels." *J. Iron and Steel Inst.* 127 (1933) 337-389.
4. Kinzel, A. B., and Franks, R., *The Alloys of Iron and Chromium*, Vol II, McGraw Hill, New York (1940) 376-389.
5. Zapffe, C. A., *Stainless Steels*, American Society for Metals, Cleveland, (1949) 289-297.
6. Thielsch, H., "Physical Metallurgy of Austenitic Stainless Steels," *WELDING JOURNAL*, 29(12), Research Suppl., 577-s to 621-s (1950).
7. LaQue, F., "Introductory Summary," *Symposium on Evaluation Tests for Stainless Steel*, Special Technical Publication No 93, Am. Soc. Testing Materials, Philadelphia (1950) 1-40.
8. Linnert, G. E., and Larrimore, R. M., "How to Control Carbide Precipitation," *Materials & Methods*, (Nov. 1953) 98-103.
9. Marshall, M. W., "Corrosion Characteristics of Types 304 and 304L Weldments," *WELDING JOURNAL*, 38(6), Research Suppl., 247-s to 250-s (1959).

10. Colombier, L., and Hochman, J., *Stainless and Heat Resisting Steels*, St. Martin's Press, New York, (1968).
11. Intergranular Corrosion of Chromium-Nickel Stainless Steels-Final Report, Welding Research Council Bull. No. 138, Feb 1969.
12. Warren, D., "The Effect of Sigma Phase vs Chromium Carbide on the Intergranular Corrosion of Type 316 and Type 316L Stainless Steel-Part 1," *Corrosion* 15 (April 1959) 215-220t.
13. Auld, J. R., "Effect of Heat Treatment and Welding on Corrosion Resistance of Austenitic Stainless Steels," Special Technical Publication No. 369, Am. Soc. Testing Materials, Philadelphia (1965) 183-199.
14. Nelson, G. A., *Corrosion Data Survey*, 1967 Edition, NACE, Houston (1968) 3.
15. France, W. D., and Greene, N. D., "Predicting the Intergranular Corrosion of Austenitic Steel," *Corrosion Sci* 8 (Jan. 1968)
16. France, W. D., and Greene, N. D., "Interpretation of Passive Current Maxima During Polarization of Stainless Steels," *Corrosion* 24 (Dec. 1968) 403-406.
17. Strauss, B., Schottky, H., and Hinneber, J., "Carbide Precipitation in the Heat Treatment of Stainless Non-Magnetic Chromium-Nickel Steels," *Z. Anorg. Allg. Chem.*, 188 (1930) 309-324 (German).
18. Bain, E. C., and Aborn, R. H., "Nature of the Nickel-Chromium Rustless Steels," *Trans. Am. Soc. Steel Treating*, 18 (1930) 837-873.
19. Bain, E. C., Aborn, R. H., and Rutherford, J. J. B., "The Nature and Prevention of Intergranular Corrosion in Austenitic Stainless Steels," *Trans. Am. Soc. Steel Treating*, 21 (1933) 481-509.
20. Payson, P., "Prevention of Intergranular Corrosion in Corrosion-Resistant Chromium-Nickel Steels," *Trans. Am. Inst. Mining Met. Eng., Iron Steel Div.*, 100 (1932) 306-328.
21. Beckett, F. M., "On the Allotropy of Stainless Steels," *AIME Trans.*, 131 (1938) 1-15.
22. Stickler, R., and Vinckler, A., "Morphology of Grain-Boundary Carbides and its Influence on Intergranular Corrosion of 304 Stainless Steel," *Trans. Am. Soc. Metals* 54 (1961)
23. Stickler, R., and Vinckler, A., "Electron Microscope Investigation of the Intergranular Corrosion Fracture Surfaces in a Sensitized Austenitic Stainless Steel," *Corrosion Sci.* 3 (1963) 1-8.
24. Baumel, A., et al., "Explanation of Intergranular Corrosion in Stainless Steels With Relation to the Chromium Depletion Theory," *Corrosion Sci.* 4 (1964) 89-103 (German).
25. Stawstrom, C., and Hillert, M., "An Improved Depleted-Zone Theory of Intergranular Corrosion of 18-8 Stainless Steel," *J. Iron Steel Inst.*, 207 (Jan. 1969) 77-85.
26. Holzworth, M. L., Beck, F. H., and Fontana, M. G., "The Mechanism of Knife-Line Attack in Welded Type 347 Stainless Steel," *Corrosion* 7 (1951) 441-449.
27. Ebling, H. F., and Schell, M. A., "Corrosion Resistance of Type 347 Stainless Steel After Sensitizing Heat Treatments," *Metal Progr.* (July, 1959) 94-97.
28. Rosenberg, S. J., and Darr, J. H., "Stabilization of Austenitic Stainless Steel," *Trans. Am. Soc. Metals* 41 (1949) 1261-1288.
29. Schuller, H. J., Schwaab, P., and Ternes, H., "The Influence of Stabilizing Heat Treatments on the Susceptibility of Stabilized Austenitic Chromium-Nickel Steels to Intergranular Corrosion," *Archiv Eisenhüttenwesen*, 35 (Jul. 1964) 659-666 (German).
30. Angerman, C. L., and Kranzlein, P. M., "Preferential Corrosion of Stabilized Stainless Steel Welds," *Trans. Am. Soc. Metals* 53 (1961) 443-446.
31. Heeley, E. J., and Little, A. T., "Corrosion Resistance of Some Austenitic Cr-Ni Steels of 18/8/Ti Composition," *J. Iron Steel Inst.*, 182 (March 1956) 241-255.
32. Castro, R., Devore, R., and Devin, R., "The Thermal Treatment of Stainless Steels Near the Solidus. Case of 18-8 Ti Austenitic Stainless Steel," *Mem. Sci. Rev. Met.* 59 (1962) 343-356 (French).
33. Bourrat, J., and Hochmann, J., "A Study of Knife-Line Attack in 18 Cr/Ni-Mo Stainless Steels Stabilized with Titanium," *Mem. Sci. Rev. Met.* 59 (1962) 863-877 (French).
34. Pouillard, E., and Choida, J. P., "Contribution to the Study of Knife-Line Corrosion of Stainless Steels Stabilized with Titanium and Niobium," *Mem. Sci. Rev. Met.* 64 (1967). 1025-1035 (French)
35. Cihal, V., et al., "Titanium Carbides as the Cause of Knife-Line Corrosion," *Anti-Corros. Methods Mater.* 15 (Nov. 1968) 14-15.
36. Vanderborck, Y. Paque, C., and Vilain, A., "Metallographic Study of Knife-Line Corrosion in an 18/8 Ti Steel after Simulated Welding," *Rev. Soudure No 1* (1969) 25-33 (French).
37. Houdremont, E., and Tofaute, W., "Resistance to Intergranular Corrosion of Ferritic and Martensitic Stainless Chromium Steels," *Stahl u. Eisen*, 72 (Oct. 1952) 539-545 (German).
38. Lula, R. A., Lena, A. J., Kiefer, G. C., "Intergranular Corrosion of Ferritic Stainless Steels," *Trans. Am. Soc. Metals* 46 (1954) 197-230.
39. Baerlecken, E., Fischer, W. A., and Lorenz, K., "Investigations on the Transformation Behavior, Impact Strength, and Susceptibility to Intergranular Corrosion of Iron-Chromium Alloys with Chromium Contents up to 30%," *Stahl-Eisen*, (Jun. 1961) 768-778 (German).
40. Baumel, A., "Relation Between Heat Treatment and the Corrosion Behavior of Stainless Steels with about 17 Percent Chromium in Boiling Concentrated Nitric Acid," *Archiv für das Eisenhüttenwesen*, 34 (Feb 1963) 135-146 (German).
41. Espy, R. H., "How Composition and Welding Conditions Affect Corrosion Resistance of Weldments in Type 430 Stainless Steel," *NACE Conf.*, Cleveland, March, 1968.
42. Bond, A. P., "Mechanisms of Intergranular Corrosion in Ferritic Stainless Steels," *AIME, Trans.* 246 (Oct. 1969) 2127-2134.
43. Bond, A. P., and Lizlovs, E. A., "Intergranular Corrosion of Ferritic Stainless Steels," *J. Electrochem Soc.* 116 (Sept. 1969) 1305-1311.
44. Hodges, R. J., and Gregory, E., "Some Corrosion Properties of Iron-Base Alloys," *American Vacuum Society, Vacuum Metallurgy Conference*, Pittsburgh, June 16-19, 1969.
45. Kiefer, G. C., "The Welding of Stainless Steel," *Engineering Experiment Station News* (Ohio State University), 22 (June 1950) 21-24 44-51.
46. d'A Hunt, C., Smith, H., and Coad, B. C., "The Combined Induction and Electron Beam Furnace for Steel Refining and Casting," *American Vacuum Society, Vacuum Metallurgy Conference*, Pittsburgh, June 16-19, 1969.
47. Gregory, E., and Knoth, R. J., "E-B Refining Upgrades 26Cr-1Mo Stainless," *Metal Progr.*, 97 (Jan. 1970) 114-120.
48. Hall, F. C., "Effect of Delta Ferrite on the Hot Cracking of Stainless Steel," *WELDING JOURNAL*, 46(9), Research Suppl., 399-s to 409-s (1967).
49. Ellinger, G. A., and Bibber, L. C., "Laboratory Corrosion Tests of Welded Low-Carbon Stainless Steel," U.S. Dept. of Commerce, Nat. Bur. Std., RP 963 (1937).
50. Schaeffer, A., and Thomas, R. D., "Corrosion of Molybdenum-Bearing Stainless-Steel Weld Metals," *WELDING JOURNAL*, 29(1), Research Suppl., 13-s to 24-s (1950).
51. Baumel, A., "The Influence of Delta Ferrite on the Corrosion Behavior of Weld Deposits Made with Austenitic Filler Materials," *Schweissen und Schneiden*, 19 (Jun. 1967) 264-269 (German).
52. Masi, A., and Mancini, F., "Ferrite Content of 18/8 Steels and Their Inter-crystalline Corrosion Resistance," *IVth Congress, European Coal and Steel Community*, Luxembourg, July, 1968.
53. Bloom, F. K., and Carruthers, M. E., "Accelerated Corrosion Testing of Chromium-Nickel Stainless Steel Weldments," *Symposium on Evaluation Tests for Stainless Steels*, Am. Soc. Testing Materials, Spec. Tech. Publ. No. 93, 1950 87-102.
54. Carruthers, M. E., "Weld Corrosion in Type 316 and 316L Stainless Steels and Related Problems," *WELDING JOURNAL*, 38(6), Research Suppl., 259-s to 267-s (1959).
55. Campbell, H. C., "Identifying Corrosion and Welding Failures in Stainless Steels," *Materials Protection* 2 (Oct. 1963) 39-42, 44.
56. Daemen, R. A., and Dept, F., "Submerged-Arc Stainless Steel Strip Cladding," *WELDING JOURNAL*, 49(1), Research Suppl., 33-s to 40-s (1970).
57. Lymonie, C., "The Corrosion Resistance of Welds in 18-10 Mo Steel to Boiling Nitric Acid," *Anti-Corrosion*, Nov. 1968), 4-8, 18.
58. Vassal, J. M., "Metallurgical Study of Various Cases of Corrosion in Urea," *Chambre Syndicale des Producteurs d'Aciers Fins et Speciaux*, 7e Salon de la Chimie, (April 1965) 89-102 (BISI 5106).
59. Gooch, T. G., "Welding Metallurgy of Stainless Steel," *Stainless Steels*, Iron and Steel Inst., London, 1969, 77-84, 99.
60. Ratz, G. A., and Gunia, R. B., "How Accurate are Methods for Measuring Ferrite," *Metal Progr.* 95 (Jan. 1969) 76-80.
61. Kauhausen, E., and Vogels, H. A., "Successful Manufacture and Use of All-Austenitic Welding Electrodes," *Metal Progr.* 67 (Jan. 1955) 129-136.
62. Hull, F. C., "Effects of Alloying Elements on Hot Cracking of Austenitic Chromium-Nickel Stainless Steels," *Am. Soc. Testing Mater. Proc.* 60 (1960) 667-686.
63. Stewart, R. S., and Urban, S. F., "The Formation of Sigma and Its Influence on the Behavior of Stabilized 18 Per Cent Chromium-8 Per Cent Nickel Steels in Concentrated Nitric Acid," *Symposium on the Nature, Occurrence, and Effects of Sigma Phase*, Am. Soc. Testing Materials Spec. Tech. Publ. No. 110, (1951) 128-145.
64. Binder, W. O., and Brown, C. M., "Influence of Carbon and Molybdenum on the Intergranular Corrosion Resistance of Austenitic Chromium Nickel Steels With and Without Columbium," *Symposium on Evaluation Tests for Stainless Steels*, Am. Soc. Testing Materials, Spec. Tech. Publ. No. 93, (1950) 146-182.
65. Lena, A. J., "Effect of Sigma Phase on Properties of Alloys," *Metal Progr.* 66 (Aug. 1954) 94-99.
66. Warren, D., "The Effect of Sigma Phase vs Chromium Carbides on the Intergranular Corrosion of Type 316 and 316L Stainless Steel-Part 2," *Corrosion* 15 (May, 1959) 221t-232t.
67. Streicher, M. A., "Effect of Heat Treatment, Composition, and Microstructure on Corrosion of 18Cr-8Ni-Ti Stainless in Acids," *Corrosion* 20 (Feb. 1964) 57t-72t.
68. Smith, L., and Bowen, W. J., "The Occurrence and Some Effects of Sigma Phase in a Molybdenum-Bearing Chromium-Nickel Austenitic Steel," *J. Iron Steel Inst.* 158 (Mar. 1948) 295-305.
69. Albritton, O. W., and Kaldceek, P. E., "Microstructural Variations in Welded Austenitic Stainless Steels Caused by Heating at 1350F," *WELDING JOURNAL*, 47(2), Research Suppl., 73-s to 81-s (1968).
70. Holt, R. M., and Nicholson, O. P., "A Study of Sigma Phase Formation and Metastability in Stabilized Austenitic Stainless Steel," *J. Iron Steel Inst.*, 200 (Sept. 1962) 715-721.
71. Krivobok, V. N., Disc., "Corrosion of Molybdenum-Bearing Stainless-Steel Weld Metals," *WELDING JOURNAL*, 29(1), Research Suppl., 24-s to 26-s (1950).
72. Downs, G. L., "Transmission Electron Microscopy of Type 304L Stainless Steel Weldments," *Welding Ibid.*, 48(10), Research Suppl., 469-s to 472-s (1969).
73. Crooks, K. L., and Linnert, G. E., "Stainless Steel Weld Metal Overlay Linings for Pulp Digester Vessels," 15th Engineering Conference, TAPPI, Jacksonville, Florida, (October 24-28, 1960.)
74. Linnert, G. E., "Alloying During Welding," *Metals Eng. Quart.* 1 (Aug. 1961), 29-56.
75. Thielsch, H., "Stainless Clad Steels," *WELDING JOURNAL*, 31(3), Research Suppl., 142-s to 160-s (1952).
76. Funk, W. H., "Interpretive Report on Welding of Nickel Clad and Stainless

Clad Steel Plate." Welding Research Council Bull. Ser. No. 61. (June 1960).

77. Brown, E. D., Younger, R. N., Smith, A. A., and Baker, R. G., "Corrosion Behaviour of Stainless Steel Weld Metal Deposited Under Different Shielding Gases," Brit. Welding J., 11 (Oct. 1964) 526-531.

78. Hopkinson, B. E., and McDowell, D. W., "Corrosion of Stainless-Steel Welds Formed with Carbon-Dioxide Shielding," Welding J., 38 (Apr. 1959) 1888-1938.

79. "Wrought Stainless Steels," *Metals Handbook* Vol. 1 8th Edition, American Society for Metals, Cleveland, (1961) 426-427.

80. Heuschkel, J., "Weld Metal Composition Control," WELDING JOURNAL, 48(8), Research Suppl., 328-s to 347-s (1969).

81. Wood, G. C., and Whittle, D. P., "On the Mechanism of Oxidation of Iron-16.4% Chromium at High Temperature," Cor. Scien. 4 (1964) 263-292.

82. Redmerski, L., and Moskowitz, A., "Effects of Surface Treatment on Corrosion Resistance of Stainless Steels," AIME, Trans. 245 (Oct. 1969) 2165-2173.

83. Pastukhov, A. M., "The Effect of Welding Slag on the Corrosion Resistance of Welded Joints," Weld. Prod. 14 (July 1967) 79-80.

84. Pease, G. R., "Corrosion of Ni-Cr-Fe Alloys by Welding Slags," Welding Research, 21 (1956) 469s-472s.

85. Moore, K. L., "Corrosion of Furnace Tubes by Residual Welding Slag," Corrosion, 16 (1960) 26t-28t.

86. Ward, C. T., Mathis, D. L., and Staehle, R. W., "Intergranular Attack of Sensitized Austenitic Stainless Steel by Water Containing Fluoride Ions," Corrosion, 25 (Sept. 1969) 394-396.

87. Thielsch, H., "Stainless Steel Weld Deposits on Mild and Alloy Steels," WELDING JOURNAL, 31(1), Research Suppl. 60-s (1952).

88. Beran, J., "Investigation into Local Corrosion Phenomena at Welds in Stainless Steel Apparatus," Werkstoff Korr. 19 (Jan. 1968) 35-41 (German).

89. Thielsch, H., *Defects and Failures in Pressure Vessels and Piping*, Reinhold, New York (1965) 385-387.

90. Linnert, G. E., "Welding Characteristics of Stainless Steels," Metals Eng. Quart. 4 (Nov. 1967) 1-15.

91. Ruttman, W., and Gunther, T., "Problems and Measures to be taken in the Manufacture of Welded Apparatus Made From Austenitic Chromium Nickel Steels that are Susceptible to Stress Corrosion," Welding Research Abroad, II (May 1965) 2-35.

92. Loginov, A. W., and Bates, J. F., "Influence of Alloying Elements on the Stress Corrosion Behavior of Austenitic Stainless Steel," Corrosion 25 (Jan. 1969) 15-22.

93. Copson, H. R., "Effect of Composition on Stress Corrosion Cracking of Some Alloys Containing Nickel," *Physical Metallurgy of Stress Corrosion Fracture*, Interscience Publishers New York (1959) 247-267.

94. Copson, H. R., and Lang, F. S., "Austenitic Chromium-Nickel Stainless Steels Resistant to Stress Corrosion Cracking," U.S. Patent 3,159,479, December, 1964.

95. Scharfstein, L. S., "Steel Alloy," U.S. Patent 3,168,397 February, 1965.

96. Wozney, G. P., and Cramer, G. R., "An Investigation of Vibrational Stress Relief in Steel," WELDING JOURNAL, 47(9), Research Suppl., 411-s to 419-s (1968).

97. "Vibration Shakedown," Weld. Design & Fab. 42 (April 1969) 81-87.

98. Rich, S. R., "Quantitative Measurement of Vibratory Stress Relief," Weld. Eng. LIV (Feb. 1969) 44-45.

99. Scheil, M. A., "Some Observations of Stress Corrosion Cracking in Austenitic Stainless Alloys," *Symposium on Stress-Corrosion Cracking of Metals*, Am. Soc. Testing Materials—Am. Inst. Mining Met. Eng., AIME, Philadelphia, (1944) 395-410.

100. Huseby, R. A., "Stress Relieving of Stainless Steels and the Associated Metallurgy," WELDING JOURNAL, 37(7), Research Suppl., 304-s to 315-s (1958).

101. Sangdahl, G. S., "Stress-Relieving of Austenitic Stainless Steel," *Metals Handbook*-Volume 2, 8th Edition, Am. Soc. Metals, Metals Park, (1964) 253-254.

102. Cole, C. L., and Jones, J. D., "Stress Relief of Austenitic Stainless Steels," *Stainless Steels*, Iron and Steel Inst., London, 1969, 71-76.

103. Bond, A. P., and Dundas, H. J., "Effects of Composition on the Stress Corrosion Cracking of Ferritic Stainless Steels," Corrosion 24 (Oct. 1968) 344-352.

104. Brown, M. H., DeLong, W. B., and Myers, W. R., "An Appraisal of Methods for Evaluating the Corrosion Resistance of Stainless Steels," *Symposium on Evaluation Tests for Stainless Steel*, Special Technical Publication No. (3, Am. Soc. Testing Materials, Philadelphia (1950) 103-120.

105. Scharfstein, L. S., and Eisenbrown, C. M., "An Evaluation of Accelerated Strauss Testing," *Advances in the Technology of Stainless Steels and Related Alloys*, Special Technical Publication No. 369, Am. Soc. Testing Materials, Philadelphia (1965) 235-239.

106. Baumel, A., "Comparative Investigation of Stainless Chromium and Chromium-Nickel Steels with Respect to Intergranular Corrosion in Boiling Nitric Acid and Copper Sulfate-Sulfuric Acid Solutions," Stahl Eisen 84 (June 1964) 798-807 (German).

107. Schwaab, P., Schwenk, W., and Ternes, H., "Susceptibility of Stabilized and Unstabilized Austenitic Chromium-Nickel Steels to Intergranular Corrosion in Different Testing Media," *Werkstoff Korr.* 16 (Oct. 1965) 844-852 (German).

108. "Detecting Susceptibility to Intergranular Attack in Stainless Steels," ASTM Designation A262-64T, *1969 Book of ASTM Standards*, Part 3, Am. Soc. Testing Materials, Philadelphia, 1969, 195-217.

109. Brown, M. H., "The Relationship of Heat Treatment to the Corrosion Resistance of Stainless Alloys," Corrosion, 25 (Oct. 1969) 438-443.

110. Comstock, G. F., "Results of Some Plant Corrosion Tests of Welded Stainless Steels," *Symposium on Evaluation Tests for Stainless Steel*, Special Technical Publication No. 93, Am. Soc. Testing Materials, Philadelphia (1950) 200-209.

111. Zitter, H., "Testing of Welded and Unwelded Chromium-Nickel Steels for Intergranular Corrosion," *Archiv Eisenhüttenwesen* 28 (July 1957) 401-416 (German).

112. Costello, T. M., Pinnow, K. E., and Moskowitz, A., "Tests with Austenitic Stainless Steel," *Mat. Protection*, 8 (Nov. 1969) 15-18.

113. Beran, J., "Current-Density-Potential Measurements on Stainless Steels in Active Media," *Werkstoff. Korr.* 19 (Sept. 1968) 769-772 (German).

East European Welding Research News

(Continued from page 253-s)

and compared with the theoretical relationship.

- Ilyushenko, V. M. et al.: Antifriction properties and wear resistance of leaded tin bronze overlays (28-31).—The wear resistance and the coefficient of friction of leaded tin bronze overlays were determined. An anti-friction alloy with optimum composition was selected for the fabrication of bimetallic heavy duty bearings.

- Volchenko, V. N.: The classification of welding processes (32-38).—Welding is defined as an irreversible thermodynamic process associated with local changes in the state of matter and of energy. The author bases his classification of the welding processes in the fundamental concept of energy.

- Kakhovskii, N. I. et al.: Welding

of Cr-Ni-Mo single-phase austenitic steels (39-43).—The effect of manganese and nitrogen on the cracking resistance of fully austenitic welds has been studied. The nitrogen-containing Cr-Ni-Mn-Mo wire EP 690 and the ANV-17 electrodes were developed for welding the Okh 17 N 16 M 3 T, 00 kh 17 N 16 M 3 B and 000 kh 16 N 15 M 3 steels. They give welded joints of uniform strength, uniform corrosion resistance and sufficiently high ductility and toughness of the weld metal.

- Nikhinson, Yu. I et al.: Welding of the T-16M automotive chassis frame (44-46).—The results of developing a procedure for welding high carbon 45L steel are reported. It is recommended to complete the weld in two passes without preheating.

- Zhukov, V. V.: Welding gold to Kovar with the laser beam (47-48).—It is shown that gold contacts and current-carrying elements made of Kovar can be successfully joined by welding with the laser beam and that the resulting joints are of high quality.

- Rudzit, R. B. and Kaleis, M. A. Effect of the dynamics of the compression mechanism on the heat concentration in the percussion welding of T-joints (49-52).—The percussion welding of T-joints between bars and plates by the use of a compression mechanism with different dynamic properties was investigated. It is shown that the heat concentration at the point of contact can be controlled by varying the free acceleration of the electrode.

- Cherednichok, V. T. et al.: Special features of rod-to-plate joints produced by flash welding (53-56).—The interdependence of the parameters which are characteristic of the upsetting process in making T-joints and the properties of the resulting welds were studied.