Effects of Slight Compositional Variations on Type E308 Electrode Deposits

Variations within AWS specification limits produced significant variations in creep-rupture strength and ductility

BY N. C. BINKLEY, R. G. BERGGREN AND G. M. GOODWIN

ABSTRACT. Several batches of covered stainless steel electrodes (classified type E308) were procured from an industrial electrode manufacturer. Slight differences in analyzed contents of carbon, silicon, phosphorus, sulfur, and boron were achieved in the deposit by small one-at-a-time alterations of the electrode covering formulation.

Longitudinal all-weld-metal, creep-rupture specimens were taken from 1 in. thick groove welds made from each batch. Creep-rupture testing was done in air at 1200 F (650 C) and at three different static stress levels — 25,000, 20,000, and 18,000 psi (170, 140, and 125 MN/m^2) — providing rupture times from 20 to over 2000 h. The various compositional changes in the deposits, although slight, produced significant variations in rupture strength and ductility.

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The shielded metal-arc welding process provides a convenient means for assessing the influence of minor compositional variations on the degree of scatter in creep-rupture data. Of particular concern is ductility, since the literature alludes to values of 0.5% or lower total elongation in 1200 F (650 C) service (Ref. 1).

Introduction

Certain austenitic stainless steels are being considered as candidate materials for vessels and associated components for various advanced nuclear systems, such as the Liquid Metal Fast Breeder Reactor (LMFBR). In addition, many austenitic stainless steel pressure vessels are currently in service at elevated temperatures and pressures in such applications as chemical and petrochemical processing equipment. Despite this wide usage, very little data have been made available concerning the high temperature creep properties of austenitic stainless steel weld deposits. Also the limited data available in the literature show a high degree of scatter. As a result, properties of such welds are receiving intensive study at the Oak Ridge National Laboratory.

This investigation is concerned with the effects of subtle compositional variations in welds deposited from coated type E308 austenitic stainless steel electrodes. This electrode type is usually preferred for welding the 18% Cr, 8% Ni grades of austenitic stainless steel, such as type 304.

Previous work has been done concerning the effects of certain elements present in various austenitic stainless steel weld deposits. However, these investigations have usually been concerned with the influence of such elements as sulfur, carbon, phosphorus, and silicon on hot cracking tendency, tensile strength, tensile ductility, impact strength, etc. The intention of this investigation is to determine what effects various amounts of these same elements have on the 1200 F (650 C) creep-rupture properties of type E308 weld deposits. Boron has been included in these experiments, because it has been reported (Ref. 2) to improve the creep resistance of various ferrous alloys. Hopefully, the data obtained will be very useful in the development of a type E308 weld deposit that will have both high creep resistance and high rupture ductility.

Experimental Procedure

The slight differences in the chemical deposit analyses of the different electrode batches were brought about solely as a result of small one-at-a-

Table 1 — Deposit Analysis for Experimental Covered Type E308 Electrodes

Electrode batch	Chemical content, % Cr	Ni	Mn	C	Si	P	S	B
Core wire	20.02	9.80	1.80	0.025	0.28	0.005	0.006	0.001
AWS A5.4-69 Spec.	18-21	9-11	2.50[a]	0.080[a]	0.90[a]	0.040[a]	0.030[a]	
Std lime-titania	19.80	9.92	1.76	0.044	0.47	0.012	0.016	0.001
Carbon varied								
Low	19.84	10.11	1.78	0.035	0.46	0.013	0.014	0.001
High	20.70	9.91	1.84	0.074	0.52	0.013	0.015	0.001
Silicon varied								
Low	20.31	10.03	1.86	0.043	0.29	0.011	0.015	0.001
High	19.62	10.02	1.70	0.044	0.73	0.010	0.013	0.001
Phosphorus varied								
Medium	19.97	10.02	1.73	0.045	0.44	0.023	0.016	0.001
High	19.90	10.08	1.82	0.043	0.47	0.035	0.012	0.001
Sulfur varied								
Low	19.89	9.95	1.73	0.042	0.42	0.011	0.006	0.001
High	19.88	10.01	1.77	0.042	0.45	0.011	0.027	0.001
Boron varied								
Medium	20.08	10.01	1.77	0.042	0.46	0.016	0.015	0.004
High	20.03	10.01	1.80	0.042	0.47	0.017	0.015	0.006

(a) Maximum amount allowed.

time changes in electrode covering formulation. That is, several batches of experimental electrodes were made by an industrial electrode manufacturer from the same heat of type 308 stainless steel core wire, upon which several slightly different covering formulations were applied. In all cases, the coverings were of a typical "lime-titania" formulation (ac and dc reverse polarity, all-position electrode). Moreover, in no case did the adjusted deposit composition of an experimental batch of electrodes fail to meet the specification (AWS A5.4-69). Table 1 shows the various deposit analyses that were realized by a careful alteration of the applied coatings. In addition to one batch of control electrodes (nominal type E308 deposit analysis), we used batches with the following elements independently varied one at a time over the extreme ranges allowed by the specification: carbon, silicon, phosphorus, sulfur, and boron. Also shown in Table 1 are the AWS A5.4-69 deposit analysis requirements and the core wire analysis.

A weld typical of one that might be used for a vessel application was made from each experimental batch of electrodes. Extreme care was taken to assure that each weld was as nearly identical to the others as possible. Using 1 in. thick (25 mm), type 304 stainless steel base metal coupons removed from the same large plate, the welds were made from one side only with a fully penetrating U-groove joint configuration. The exact joint geometry involved an 80 deg included angle with a 1/8 in. (3 mm) root face and root opening. A 3/16 in. thick (5 mm), type 304 backing strip was also used for the root pass. This geometry was used to yield the maximum number of all-weld-metal, longitudinal creep-rupture specimens from each 32 in. long (81 cm) weld, Before welding, the electrodes were baked at 250 F (120 C) for about 1 h to remove moisture, and the plates were thoroughly cleaned. Excellent welding technique was used at all times; that is, much attention was given to current control (approx. 140 A), deposit technique, travel speed (about 10 ipm, 4 mm/sec), slag removal, interpass temperature (max 250 F or 120 C) and back grinding of craters. Arc voltage averaged 26 V. Most importantly, the same welding machine and highly qualified welding operator were used throughout the program. As a result, the completed welds were all radiographically sound and identical in appearance.

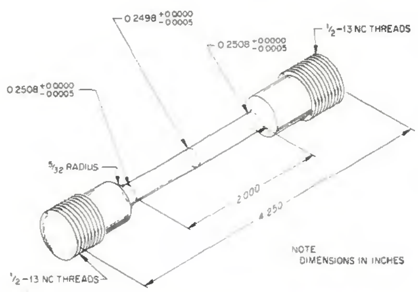

Fig. 1 — Threaded creep-rupture specimen for experimental stainless steel deposits (1 in. = 25.4 mm)

Figure 1 shows the longitudinal, all-weld-metal creep-rupture specimen that was used throughout this investigation. The specimens, with 1/4 in. diam by 2 in. long (6.4 × 51 mm) gage sections, were end threaded for use in lever-arm creep machines. Three such specimens could be removed per each 4 1/2 in. (115 mm) length of weld deposit. Creep-rupture tests were then conducted in air at 1200 F (650 C) and at three different static stress levels: 25,000, 20,000, and 18,000 psi (170, 140, and 125 MN/m^2).

The various compositional changes in the deposits, however slight, produced significant variations in rupture strength and ductility. The three stress levels provided rupture times from 20 to over 2000 h. Ductilities ranged from much less than 1% to over 30% total elongation over the 2 in. long (51 mm) gage section.

Table 2 shows the results of the creep tests at the 25,000 psi (170 MN/m^2) stress level. Since most of the rupture lives were less than 50 h, these results can really be used only to make very rough generalizations. However, one can see immediately that the carbon content has a very marked effect on the high temperature strength of type E308 filler material. The rupture life of the high carbon deposit (0.074% C) was almost six times that of the "standard" (0.044% C) deposit. Notice also that the two boron-doped deposits had increased rupture lives, and their rupture ductilities exceeded 30% total elongation. Lower amounts of silicon and higher amounts of phosphorus and sulfur also seem to increase the rupture ductility significantly.

Table 3 shows the results of the creep tests run at 1200 F (650 C) under 20,000 psi (140 MN/m^2) static stress. The differences in creep behavior of the various altered deposits

Table 2 — Effect of Composition Variables on the Creep-Rupture Properties of Shielded Metal-Arc Stainless Steel Welds at 1200 F (650 C) and 25,000 psi (170 MN/m²)

Compositional variables	Rupture time, h	Total elong., %
Std lime-titania covering[a]	44.0	10.2
Carbon, %		
Low, 0.035	31.5	22.0
High, 0.074	254.3	11.3
Silicon, %		
Low, 0.29	40.0	26.7
High, 0.73	27.0	16.3
Phosphorus, %		
Medium, 0.023	49.4	22.5
High, 0.034	47.0	31.4
Sulfur, %		
Low, 0.006	48.0	15.5
High, 0.027	31.0	31.4
Boron, %		
Medium, 0.004	63.7	36.0
High, 0.006	71.3	30.0

(a) 0.044%C, 0.47%Si, 0.012%P, 0.016%S, 0.001%B.

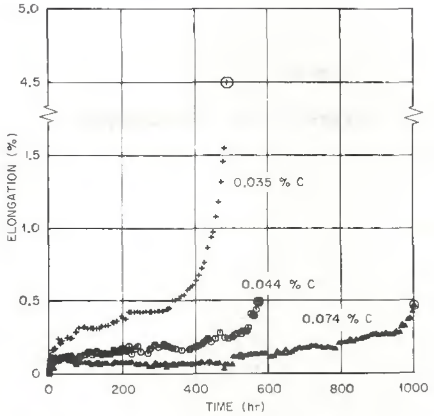

Fig. 2 — Effect of carbon content on the creep of Type E308 stainless steel weld metal at 1200 F (650 C) and 18,000 psi (125 MN/m²).

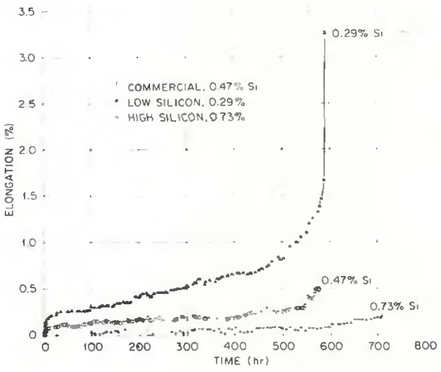

Fig. 3 — Effect of silicon content on the creep of Type E308 stainless steel weld metal at 1200 F (650 C) and 18,000 psi (125 MN/m²)

Table 3 — Effect of Compositional Variables on the Creep Properties of Shielded Metal-Arc E308 Stainless Steel Welds at 1200 F (650 C) and 20,000 psi (140 MN/m²)

Compositional variables	Rupture time, h	Total elong., %
Std lime-titania covering[a]	363	2.0
Carbon, %		
Low, 0.035	346	4.0
High, 0.074	1334	1.75
Silicon, %		
Low, 0.29	127	15.7
High, 0.73	651	1.3
Phosphorus, %		
Medium, 0.023	166	9.6
High, 0.034	1329	4.35
Sulfur, %		
Low, 0.006	333	2.6
High, 0.027	292	4.05
Boron, %		
Medium, 0.004	1167	7.5
High, 0.006	1159	7.8

(a) 0.044% C, 0.47% Si, 0.012% P, 0.016% S, 0.001% B.

become more apparent at the lower stress levels and the resulting longer rupture times. Again, the deposit of higher carbon content proved to be much stronger than the "standard" deposit under these conditions. Lowering the carbon content below the "standard" did not appear to have any significant effect on the rupture life of the deposit, but it did increase rupture ductility. Adding boron to the type E308 deposit again seemed to improve significantly both the rupture life and the rupture ductility. Lowering the amount of silicon in the type E308 deposit very markedly increased the final rupture ductility, but this effect is probably due to a corresponding loss of rupture life. There seems to be very little difference as a result of sulfur content.

Table 4 shows the results of the long time creep-rupture tests at the 18,000 psi (125 MN/m²) stress level. Failure of these specimens after the relatively long rupture lives was usually accompanied by very low rupture ductilities. Those deposits that failed with over 2% total elongation at this stress level did so only at the sacrifice of rupture life. Therefore, it is difficult to say that reducing the content of silicon and carbon in type E308 deposits results in any better resistance to the long time creep embrittlement. However, it has become apparent that additions of phosphorus and boron significantly strenghten the weld deposit and add a certain measure of resistance to creep embrittlement when compared with other type E308 deposits.

Figure 2 shows the effect of carbon content on creep of the deposit at 1200 F (650 C) and 18,000 psi (125 MN/m²). Although none of the compositions exceeded the 0.08% C maximum allowed by the AWS A5.4-69 specification for type E308, one should note that the 0.035% C deposit also complied with the more stringent E308L classification. It is immediately obvious from Fig. 2 that carbon is a potent strengthener. The 18,000 psi (125 MN/m²) and 1200 F (650 C) creep life of the 0.074% C deposit was over twice that of the 0.035% C deposit. The 0.044% C deposit fractured with much less ductility than the 0.035% C deposit, but with no more ductility than the 0.074% C deposit.

The effect of silicon content at 18,000 psi (125 MN/m²) and 1200 F (650 C) is shown in Fig. 3. There appeared to be very little difference among the three deposits as to rupture life, since all three failed within 576 to 710 h. However, there was a very noticeable effect upon the rupture ductilities. Notice that the 0.29% Si deposit fractured with nearly 3.5% elongation after a test exposure of almost 600 h. The higher silicon deposits fracture with less than 0.5% elongation. It appears that a lower silicon content in the deposit will yield a more ductile weld without severely weakening the deposit.

The effect of phosphorus content at 18,000 psi (125 MN/m²) and 1200 F (650 C) is shown in Fig. 4. It appears that additions of phosphorus are actually beneficial to the creep properties of the deposit. In the case of phosphorus, the "standard" deposit contained the lowest amount of phosphorus (0.012%). The two experimental phosphorus electrode deposits contained 0.023 and 0.034% P. Like carbon, phosphorus appears to be a potent strengthener, as indicated by the much increased rupture lives of the doped deposits. However, unlike the carbon additions, the added phosphorus has also increased the rupture ductility rather markedly. The medium phosphorus deposit showed a total elongation of 2.2% after an exposure of 1332 h to the test conditions. Even the high phosphorus deposit had nearly 1% total elongation after an exposure of 1655 h. These total elongations after such long exposures indicate that phosphorus additions can increase both rupture life and total elongation rather dramatically for the type E308 deposit.

The effect of sulfur content is shown in Fig. 5. There does not appear to be a systematic effect as a result of the sulfur content on the creep properties of type E308 deposits at 18,000 psi (125 MN/m²) and 1200 F (650 C). Rupture lives vary only from 500 to 600 h, and total elongations range from 0.5% to slightly less than 0.8%. The three deposits behaved very similarly, probably due to the relatively high amount

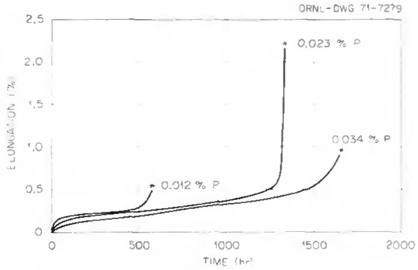

Fig. 4 — Effect of phosphorus content on the creep of Type E308 stainless steel weld metal at 1200 F (650 C) and 18,000 psi (125 MN/m²)

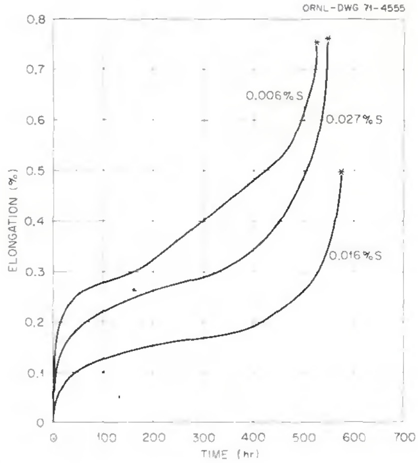

Fig. 5 — Effect of sulfur content on the creep of Type E308 stainless steel weld metal at 1200 F (650 C) and 18,000 psi (125 MN/m²)

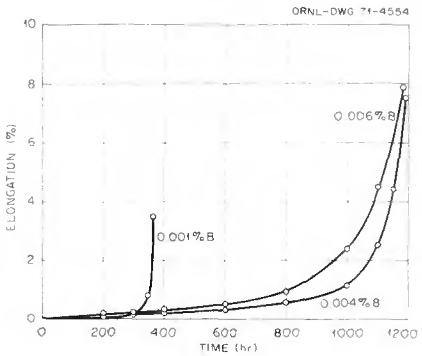

Fig. 6 — Effect of boron content on the creep of Type E308 stainless steel weld metal at 1200 F (650 C) and 20,000 psi (140 MN/m²)

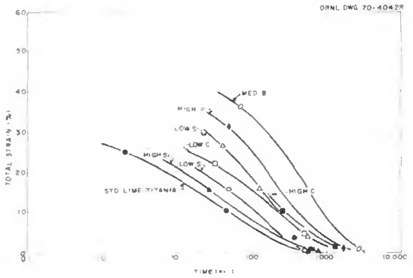

Fig. 7 — Effect of composition on the creep ductility of shielded metal-arc welds at 1200 F (650 C)

of manganese (about 1.80%) present in each deposit, since manganese is well known as an effective scavenger of sulfur.

Figure 6 shows the effect of boron content on the 20,000 psi (140 MN/m²) and 1200 F (650 C) creep behavior of type E308 deposits. Interestingly, there is no specification concerning the amount of boron allowed in a type E308 deposit. The "standard" deposit had a low boron level (0.001%). The boron doped deposits behaved very similarly to the phosphorus doped deposits. That is, adding boron increased both the rupture life and the rupture ductility of the deposit. Boron proved to be such a potent strengthener that the medium boron (0.004%) deposit had a rupture life of 2670 h when creep tested at 18,000 psi (125 MN/m²) and 1200 F (650 C). Hence, the high boron (0.006%) deposit was not tested at 18,000 psi (125 MN/m²) and 1200 F (650 C), in anticipation of an extraordinarily long rupture life. At the 20,000 psi (140 MN/m²) stress level shown in Fig. 6, the boron doped deposits behaved equally well, having rupture lives and ductilities of about 1200 h and 8% total elongation. The 8% total elongations after exposures of nearly 1200 h were, by far, the two best creep performances of any of the deposits tested in this investigation.

Figure 7 summarizes the effect of composition on the creep ductility of the type E308 deposits studied in this investigation. If one would imagine the lines missing, it would become apparent how difficult it is to assemble good creep ductility data on a certain type of weld deposit, such as type

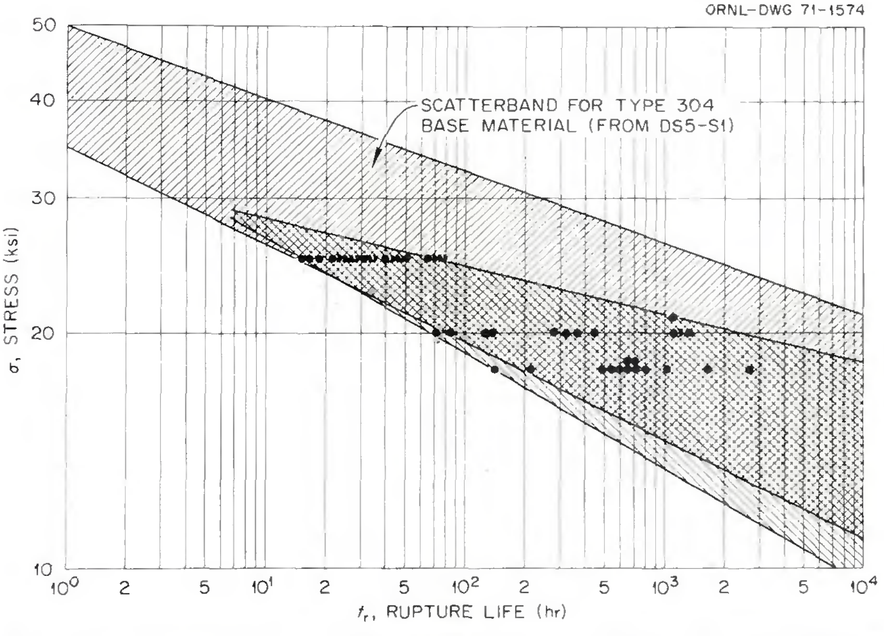

Fig. 8 — Creep-rupture properties of Type E308 stainless steel shielded metal-arc welds at 1200 F (650 C)

Table 4 — Effect of Compositional Variables on the Creep-Rupture Properties of Shielded Metal-Arc E308 Stainless Steel Welds at 1200 F (650 C) and 18,000 psi (MN/m²)

Compositional variables	Rupture time, h	Total elong., %
Std lime-titania covering [a]	576	0.50
Carbon, %		
Low, 0.035	490	4.5
High, 0.074	1004	0.46
Silicon, %		
Low, 0.29	592	3.2
High, 0.73	710	0.2
Phosphorus, %		
Medium, 0.023	1332	2.2
High, 0.034	1655	0.97
Sulfur, %		
Low, 0.006	526	0.75
High, 0.027	548	0.67
Boron, %		
Medium, 0.004	2670	0.98

(a) 0.044% C, 0.47% Si, 0.012% P, 0.016% S, 0.001% B.

E308. Nevertheless, it can be seen from Fig. 7 that the boron doped deposit (0.004% B) demonstrates the best creep ductility for any given rupture life. The high phosphorus deposit (0.35% P) was the next best, followed by the low silicon deposit (0.20% Si). Somewhat disquieting was the fact that all the deposits tended toward zero ductility with extended rupture lives. Again, the boron doped deposits, as well as the high phosphorus and low silicon deposits, appeared to be most resistant to this phenomenon. Interestingly, the standard composition curve falls at the lower boundary of the family of curves.

Figure 8 shows all the data accumulated in this investigation concerning rupture lives for the various type E308 deposits. These data have been superimposed upon the stress-rupture scatter band for type 304 base material, obtained from ASTM DS 5-S1 (Ref. 3). The rupture-life data have been plotted for the three different stress levels, and a type E308 weld deposit scatter band is suggested, based on the 1200 F (650 C) data obtained by examining all the practical compositional limits of the typical E308 weld deposit. Interestingly enough, while the data of this investigation suggest a very wide rupture-life scatter band, it still remains well within the extremely wide rupture-life scatter band for the type 304 base materials.

Discussion of Results

Previous work by the authors (Ref. 4) has definitely indicated that the trend toward loss of ductility in the type E308 deposit is a result of the time-dependent formation of sigma phase that can occur at 1200 F (650 C). Sigma phase has been metallographically identified and positively associated with the formation of the ferrite-austenite phase-boundary cracking of the embrittled type E308 creep specimens.

It follows that this sigma phase formation reaction can be somewhat retarded by minor adjustments in the deposit chemical composition. Referring to Fig. 7, one can see that the resistance to creep embrittlement is improved markedly by small additions of boron to the E308 deposit. While the result from the high boron (0.006%) deposit is not shown, one can expect that it would lie somewhat to the right of the medium boron (0.004%) deposit data. Note also that slight additions of phosphorus improve the resistance to embrittlement. One could further suggest that a slight reduction in the silicon content of the E308 deposit would increase the resistance to embrittlement.

The carbon content of the weld deposit appears to determine only the deposit's relative creep strength. That is, a higher carbon level would serve only to yield a longer rupture life for any given stress level at 1200 F (650 C). There is no evidence to suggest that any particular level of carbon content is more resistant to long term embrittlement than any other. Clearly the sulfur content levels studied had no effect on either the creep strength or the resistance to creep embrittlement.

The data assembled as a result of this investigation can be quite valuable as an aid to the development of a special type E308 shielded metal-arc electrode that combines both high creep strength and good resistance to embrittlement. One might expect such an electrode to yield a deposit analysis that is high in boron (approx. 0.005%), high in phosphorus (approx. 0.035%), low in silicon (approx. 0.025%), and somewhat high in carbon (approx. 0.06%) to assure good creep strength. If proper care is taken in the covering formulation to assure good arc stability and adequate deoxidation and slag formation, such an electrode promises to yield a deposit that would exhibit excellent creep properties. The proposed electrode deposit would, hopefully, yield total strain curves that would fall far to the right of those in Fig. 7. Moreover, the creep strength of such a deposit should be quite high, appearing in the vicinity of the upper limit of the suggested scatter band for type E308 deposits shown in Fig. 8.

As a final note, the welding operator who deposited all the experimental batches of type E308 electrodes used in this investigation could detect essentially no difference in the welding performance of any single batch. Therefore, one should expect no welding performance abnormalities as a result of the slight compositional changes that have been suggested for the E308 electrode deposit.

Conclusions

The conclusions reached in this investigation concerning the effects on creep properties at 1200 F (650 C) of slight compositional variations in standard type E308 stainless steel electrodes on shielded metal-arc deposits include:

1. Increasing the carbon content of the deposit up to the maximum, 0.08%, serves only to increase creep strength. Carbon content seemingly has no effect on preventing creep embrittlement.

2. Reducing the silicon content of the deposit to about 0.29% appears to improve resistance to creep embrittlement without seriously lessening creep strength.

3. Higher phosphorus contents of the deposit to 0.034% evidently improve both creep strength and resistance to creep embrittlement.

4. Sulfur content within the allowable limits has essentially no effect on either creep strength or resistance to creep embrittlement.

5. Additions of boron to the deposit up to about 0.006% have a markedly beneficial effect, improving both creep strength and resistance to creep embrittlement.

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STRUCTURAL WELDING CODE

Incorporates all of the welding requirements for the construction of buildings, bridges, and tubular structures.

Published in September, 1972, the Structural Welding Code, AWS D1.1-72, combines into a single document, completely updates, and replaces the Code for Welding in Building Construction, AWS D1.0-69, and Specifications for Welded Highway and Railway Bridges, AWS D2.0-69. Also, for the first time anywhere, requirements are presented for the design and fabrication of welded tubular structures.

These are the major changes affecting the building and bridge requirements which have been incorporated into the Code: (1) the addition of requirements for visual inspection for and repair of defects in cut edges of plates as received from the mill, (2) revision of weld quality and inspection requirements to remove ambiguity in previous editions relative to visual and nondestructive examinations, (3) increased tolerances on warp and tilt of girder flanges, and (4) inclusion of revisions issued in April of 1970*, including those to permit use of gas metal-arc (GMAW) and flux cored arc welding (FCAW) with prequalified procedures. Fatigue stresses for use in bridge design have been extended to include all steels used under the bridge portion of the Code.

To save time in the use of the Code, there is a complete index, an appendix containing selected definitions from Terms and Definitions, AWS A3.0-69, plus other welding terms used in the Code, and an appendix for conversions to the metric (SI) system. The Code is three-hole punched to permit insertion in binders if desired and to provide for the inclusion of revisions as issued. Its 8½ in. × 11 in. size is easier to read and use than the previous 6 in. × 9 in. editions of the Building Code and Bridge Specifications.

CONTENTS

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