Hot Cracking Problems in Different Fully Austenitic Weld Metals

An analytical tool known as the PVR test accurately characterizes the tendency of materials to solidification and liquation crack formation

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ABSTRACT. With primary ferritic solidifying stainless steel weld metal alloys, the problems of solidification as well as liquation cracking are completely under control. This is true also with Nb-stabilized types, where besides the austenite, a certain minimum quantity of so-called delta-ferrite is to be found in the austenitic microstructure.

To avoid solidification cracks in primary austenitic solidifying stainless steel weld metal alloys which are also fully austenitic at room temperature, it is necessary to bring specific alloy components, like manganese, into line. As far as today's knowledge goes, it is hardly possible to completely avoid microliquation cracks in fully austenitic weld metals in very rigid weldments which are extremely restrained with respect to shrinkage. But as test results show, it is possible to influence the number of liquation cracks under certain conditions.

Ten different corrosion resistant weld metal alloys, most of them fully austenitic, were examined using a newly developed hot cracking test, the "Program Controlled Deformation Cracking Test" also called PVR test (Programmierter-Verformungs-Risstest). By means of this test, it is possible to determine the limits of deformability of weld metal with respect to the formation of solidification and liquation cracks. There were four critical deformation rates through which at least an approximate correlation to the behavior in practical weldments could be found.

All methods to avoid solidification cracks are, in principle, usable for reducing the number of liquation cracks in fully austenitic stainless steel weld metals. Increases in the contents of specific elements like manganese and molybdenum (compared to the lower contents of specific elements – for example, silicon and niobium) have an advantageous effect on the reduction of the number of liquation cracks. Also, the susceptibility of the weld metal to cracks becomes greater at higher shrinkage stresses as the absolute level of the total alloying content becomes higher.

Besides factors that influence liquation cracking sensitivity, there is the great distance of the Cr-Ni-equivalent in the DeLong diagram from the boundary line to the area of austenitic weld metals with certain ferrite levels. The lowest contents of delta-ferrite of FN 0 to 1 have a very positive influence on the resistance against liquation cracks. Those ferrite levels, on the other hand, still have no influence on the sensitivity to solidification cracking.

Introduction

Austenitic Cr-Ni corrosion resisting steels have been welded successfully for decades. Through the years it has been known that austenitic weld metal is qualitatively satisfactory if the microstructure, besides austenite, shows a certain minimum quantity of so-called delta-ferrite. If less than the minimum amount is present, hot cracks may form. Today, we know that a correlation exists between the primary crystallization cycle and the resistance against hot cracking. As a result, the delta-ferrite measured at ambient temperature is only residual ferrite present in dendritic form shortly after solidification (Ref. 1, 2).

The trend in the area of chemical processes and energy development toward increased output as well as completely new processing engineering methods has led to modified or newly developed steel grades and welding filler metals. In this connection, the requirement for a fully austenitic weld metal is greater than ever before. This is because of maximum corrosion resistance, great ductility at subzero temperatures and non-magnetizability. In this respect, the whole problem of crack-free production of a fully austenitic weld metal becomes important; where the distinction between solidification and liquation cracking is an absolute necessity.

Many methods have been developed to determine the tendency to solidification cracking of fully austenitic weld metals. Today, like before, the separate detection and effect of liquation cracks, besides solidification cracks, is a subject of basic research work.

The object of the research described in this paper was, through the development of a suitable testing method, to study the effects on the susceptibility to solidification and liquation crack formation of highly corrosion resistant weld metal alloys. It was assumed that both types of hot cracks could be determined on one specimen and that it would be possible to vary the deformations of the specimen to a wide extent during testing. This was done in order to obtain a practical evaluation of the behavior of the material in weldments of various thicknesses and chucked differently.

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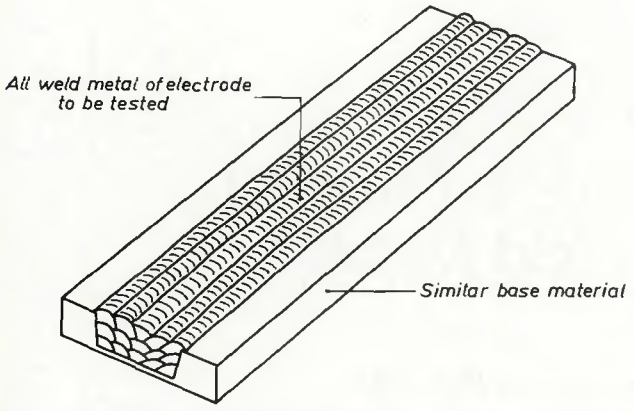


Fig. 1—PVR specimen: filled groove with all-weld-metal to be tested

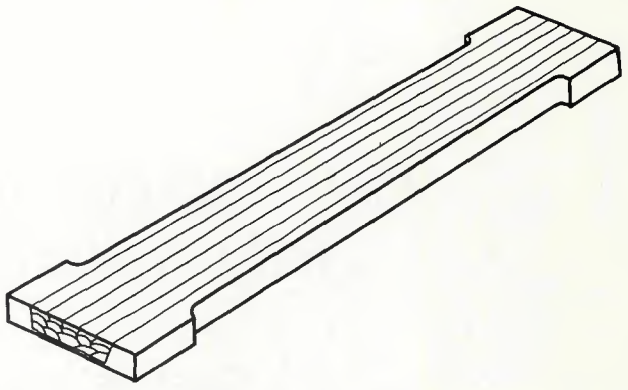


Fig. 2—PVR test: machined and surface controlled specimen before testing

Program Controlled Deformation Cracking Test (PVR Test)

In order to meet the above stated requirements, the so-called PVR-test was developed (Ref. 1). Figure 1 shows the detail of the specimen used. The rectangular groove of a flat tensile specimen, e.g., grade AISI 316 L, is filled up with 3 layers, 5 runs each, using weld metal of the 4 mm (5⁄32 in.) diameter covered electrode to be tested. Following alignment, the specimen is ground flush with the plate up to about half of the top layer, etched and before actual examination checked for possible micro-cracks, magnified 40 times— Fig. 2.

The specimen is then clamped onto a programmable horizontal tensile testing machine (Fig. 3) and prestressed immediately below the apparent yielding point. After that, a test bead of similar electrode grade is welded on along the middle axis of the filled-up groove, whereby the sample is simultaneously deformed at a preprogrammed, linearly increasing deformation rate. The maximum deformation rate at the machine amounts to about 70 mm/min (2.75 ipm).

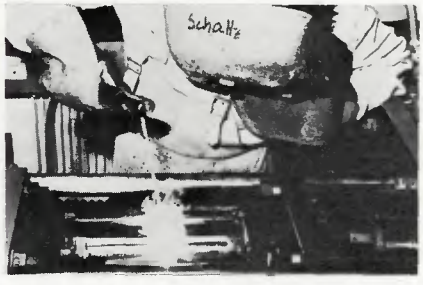


Fig. 3—Welding during PVR testing

Evaluation of the specimen is done as follows:

1. The last welded bead is examined visually for solidification cracks using the dye penetration test—Fig. 4.

2. After grinding the bead flush to the plate, it is polished and etched with a special solution consisting of 2 parts HCl, 1 part HNO_3 and 1 part H_2O_2 (Ref. 4).

3. Microcracks (magnified 40 times) are determined in the last welded test bead (solidification cracks) and in both heat-affected zones next to the test bead (liquation cracks). (Figure 5 shows an analyzed PVR test specimen of a fully austenitic weld metal; the cracks were marked macroscopically by a color mark.)

4. Upon individual counting of the solidification and liquation cracks, the susceptibility of the weld metal to cracking is evaluated as follows:

- Critical deformation rate V1, whereby for the first time 3 liquation cracks per 10 mm (0.4 in.) of bead length appear in both heat-affected zones next to the test bead.
- Critical deformation rate V2 for the accumulation of liquation cracks. This is the deformation rate whereby for the first time 9 liquation cracks per 10 mm (0.4 in.) of bead length occur in both heat-affected zones next to the test bead.
- Critical deformation rate V3, whereby the first solidification crack is encountered, magnified 40 times on the test bead which was machined flush to the plate (micro solidification crack).
- Critical deformation rate V4, whereby the first solidification crack is discovered following visual examination in the last welded and unmachined test bead (macro solidification crack).

Fissure Bend Test

To the extent possible, PVR test results were compared with the fissure bend test developed in the United States. In this test, only one elastic and/or plastic deformation is simulated by a rigid restraint. It should be noted that for the fissure bend test, 4 mm (5⁄32 in.) diameter electrodes were used to have a better basis for comparison with the PVR test. This is contrary to a suggestion in the literature (Ref. 5). The specimen was assembled by depositing two buffer lay-

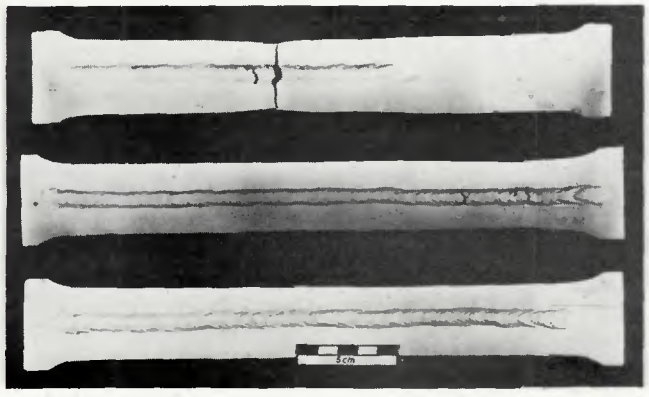


Fig. 4—PVR test: examination for macro-solidification cracks. Top two specimens—with cracks; bottom specimen—without cracks

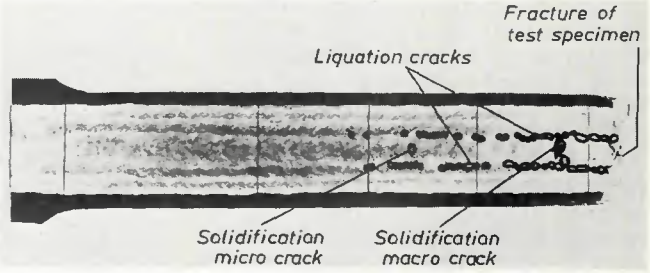


Fig. 5—Appearance of examined PVR test specimen

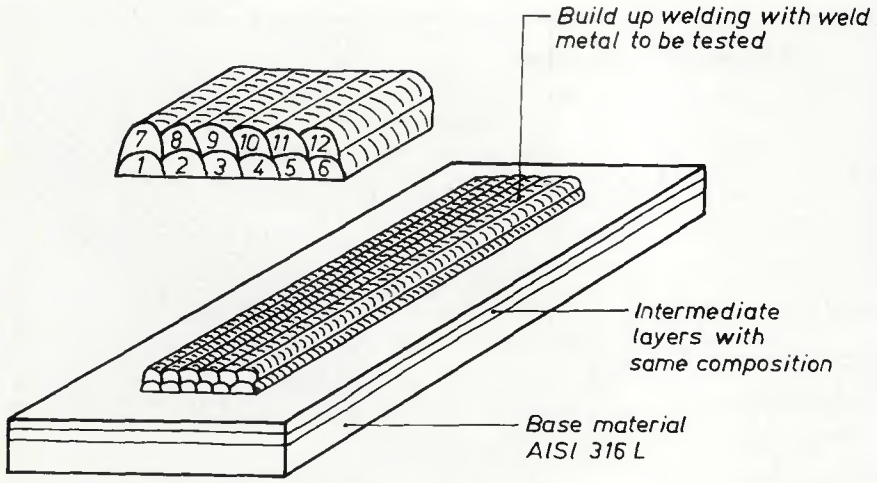


Fig. 6 — Schematic design of fissure bend test specimen

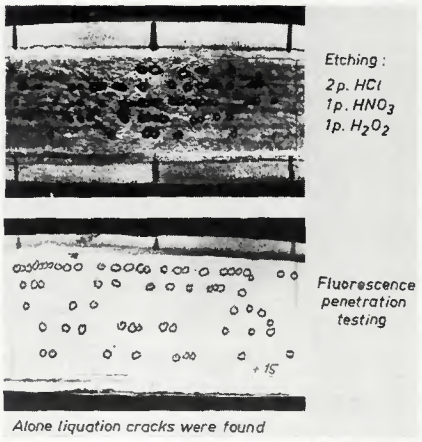


Fig. 7 — Appearance of fissure bend test specimens after testing (fully austenitic weld metal)

ers of weld metal (using the electrode to be tested) on AISI 316L stainless steel plate and then building up two layers with 6 beads each on the two buffer layers (again using the electrode to be tested) — Fig. 6.

Counting the cracks in the unbent and bent conditions was done, on the one hand, according to the fluorescence penetration test described in the literature (Ref. 5). In addition, this was carried out by using specially etched specimens (2 parts HCl, 1 part HNO_3, 1 part H_2O_2) magnified 40 times. Figure 7 shows two fissure bend test samples of a fully austenitic weld metal alloy analyzed according to both methods, whereby the microcracks were made visible macroscopically through color marking.

Test Alloys

Table 1 contains the chemical composition and the measured ferrite (FN) values of the pure weld metal of the alloys examined.

From a solidification viewpoint, alloys A and B are two fundamentally different Cr-Ni weld metal alloys, while alloy B matches AWS E 308 L. Figure 8 shows the position of both alloys in the ternary system Fe-Cr-Ni, according to Schürmann (Ref. 6), at a concentration level of 20% Cr. Alloy A solidifies primarily fully austenitic as gamma crystals and does not contain any delta-ferrite in the weld metal, even at room temperature. It should be noted that, with the fully austenitic alloy A, no alloying measures were taken to improve the hot-cracking resistance; these measures were not taken in order to study the behavior during the hot-cracking test in comparison with the other alloys.

Alloy B solidifies primarily ferritic as delta crystals and has a residual ferrite content of approximately 5 FN at room temperature. Alloy C conforms to the weld metal of a commercial electrode according to AWS E 316 L-16.

Special electrodes — types D and E — which are commercially available and yield a fully austenitic weld metal, differ above all by their differing manganese and silicon content and by the different nature of their coverings. Rutile-covered electrode D is used for weldments of relatively thin wall thicknesses in chemical equipment for the manufacturing of pharmaceutical products; lime-based electrode E is used at cryogenic ranges down to 4 Kelvin (−269°C or −452°F).

Newly developed basic specialty electrode F, which yields a fully austenitic weld metal with especially high molybdenum content, is primarily used for welding steels with significant resistance against pitting and crevice corrosion.

High-alloy electrode G conforms to AWS E 320-15. As is well known, this type is used for welding stabilized specialty steels with high resistance against sulfuric acids with concurrent good resistance against stress corrosion cracking and general erosive corrosion.

Today, type H1, H2 and H3 electrodes are used for welding low carbon steels with 25% Cr and 22% Ni for modern urea plants. The weld metal of basic electrode H1 contains insignificant delta ferrite of 0 to 1 FN. Because of its higher Ni-content, alloy H2 of basic electrode H2 falls entirely within the pure austenite range, according to the DeLong diagram (Ref. 7). Contrary to H2, electrode H3 is a mixed type (between a rutile and basic covered electrode) and its weld metal contains only 3% manganese.

Variants H1, H2 and H3 were specially selected in order to study the liquation cracking problem, because this is of such great importance for process tests in the construction of urea installations (Ref. 4).

Figure 9 shows the position of the individual weld metal alloys in the expanded DeLong diagram (Ref. 7). The

Table 1—Tested Covered Electrodes or Weld Metals

Designation	Type of covering	AWS designation	Chemical composition of all weld metal, %									Ferrite Number, N[(a)]
			C	Si	Mn	Cr	Mo	Ni	Cu	Cb	N_2	
A	Basic	—	0,029	0,43	1,54	19,19	—	14,17	—	—	—	0
B	Basic	E 308L	0,030	0,47	1,64	19,84	—	10,80	—	—	—	5
C	Rutile	E 316L	0,025	0,85	0,79	18,50	2,50	12,21	—	—	—	9,3
D	Rutile	—	0,018	0,67	0,76	17,59	2,56	16,52	—	—	—	0
E	Basic	—	0,032	0,16	4,54	16,88	2,06	16,13	—	—	—	0
F	Basic	—	0,036	0,36	4,29	19,64	7,46	25,25	2,45	—	—	0
G	Basic	E 320	0,038	0,27	2,45	20,31	2,56	34,34	2,93	0,45	—	0
H1	Basic	—	0,031	0,35	5,41	25,31	2,00	19,60	—	—	0,10	0-1
H2	Basic	—	0,036	0,16	5,44	24,62	1,72	22,64	—	—	0,17	0
H3	Rutile-basic	—	0,036	0,25	3,02	24,74	2,31	22,57	—	—	0,22	0

[(a)]Tested with Förster 1.053 instrument (102 C.314) — instrument calibrated to FN.

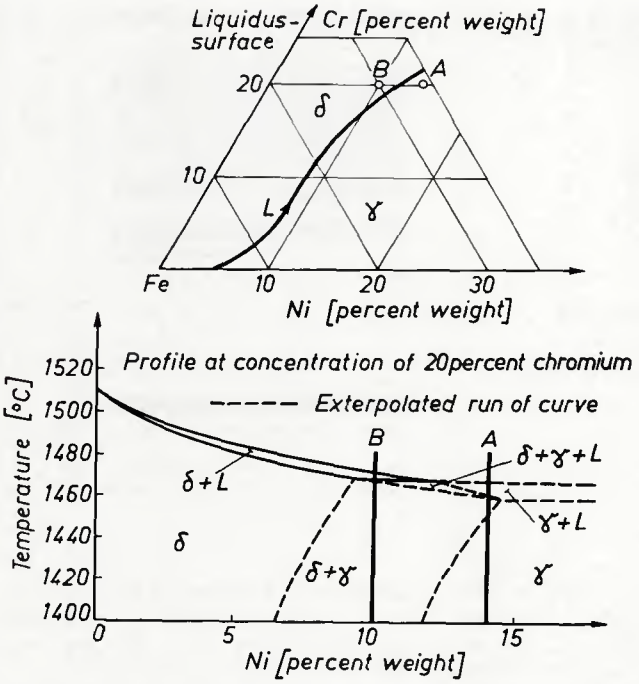


Fig. 8—Position of alloys in the ternary system Fe-Cr-Ni (by Schürmann)

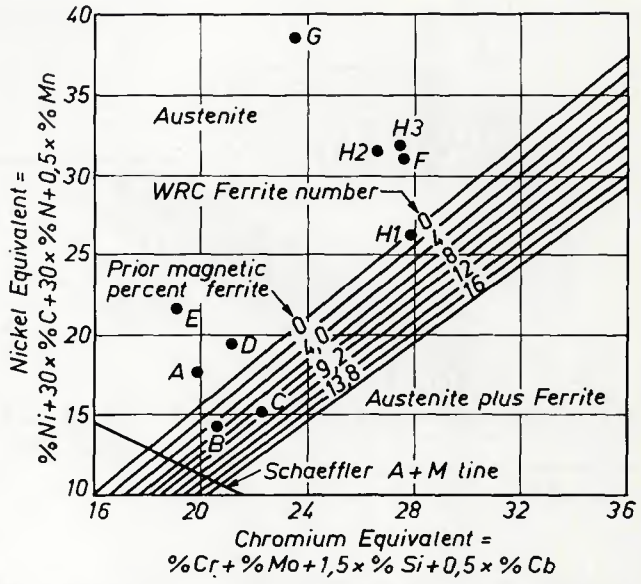


Fig. 9—Position of tested alloys in the DeLong constitution diagram

Table 2—Elevation of the PVR Tests (Average Values of Two Test Specimens)[a]

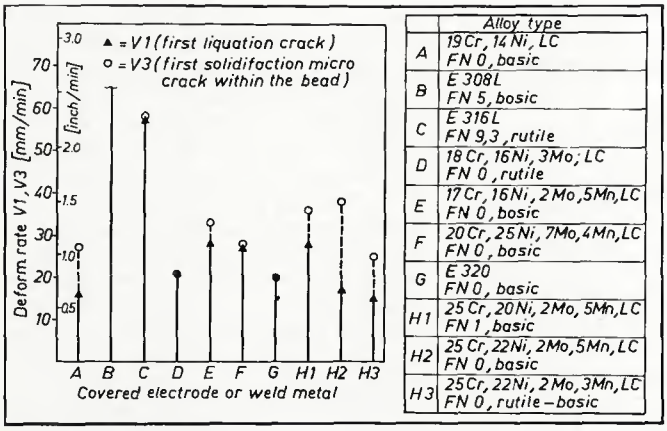
Electrode or weld metal	Alloy type	Tendency to liquation cracking: Number of cracks in test field, ipm: 0 to 0.79	0.79 to 1.18	1.18 to 1.57	1.57 to 1.97	1.97 to 2.36	Tendency to solidification cracking: V1[c] ipm	V2[c] ipm	V3[c] ipm	V4[c] ipm
A	19Cr, 14Ni, LC FNO, basic	6	23[b]	–	–	–	0.63	0.94	1.06	1.14
B	E 308L FN5, basic	0	0	0	0	0	> 2.56	> 2.56	> 2.56	> 2.56
C	E 316L FN 9,3 rutile	0	0	0	0	4	2.24	> 2.56	2.28	> 2.56
D	18Cr, 16Ni, 3Mo, LC FNO, rutile	3	17[b]	23[b]	32[b]	–	0.83	1.14	0.83	1.22
E	17Cr, 16Ni, 2Mo, 5Mn,LC FNO, basic	0	2	61[b]	65[b]	–	1.10	1.26	1.30	1.46
F	20Cr,25Ni,7Mo,4Mn,LC FNO, basic	0	2	3	22[b]	–	1.06	1.61	1.10	1.65
G	E320 FNO, basic	3	13[b]	–	–	–	0.79	0.91	0.79	0.79
H1	25Cr,20Ni,2Mo,5Mn,LC FN1,basic	0	3	40	82[b]	–	1.10	1.30	1.42	1.85
H2	25Cr,22Ni,2Mo,5Mn,LC FNO, basic	6	14	52[b]	–	–	0.67	1.18	1.50	1.81
H3	25Cr,22Ni,2Mo,3Mn,LC FNO,rutile-basic	5	6	9	46[b]	–	0.59	1.77	0.98	1.89

[a]Deformation rate linearly increased from 0 to 2.76 ipm.
[b]In addition, plain solidification cracks.
[c]V1 – first time cracks each cm bead length (= 2 fusion lines); V2 – first time 9 cracks each cm bead length (= 2 fusion lines); V3 – first solidification microcrack within the bead; V4 – first solidification macrocrack on the surface of bead.

Table 3—Evaluation of the Fissure Bend Test (Average Values of 2 Test Specimens)

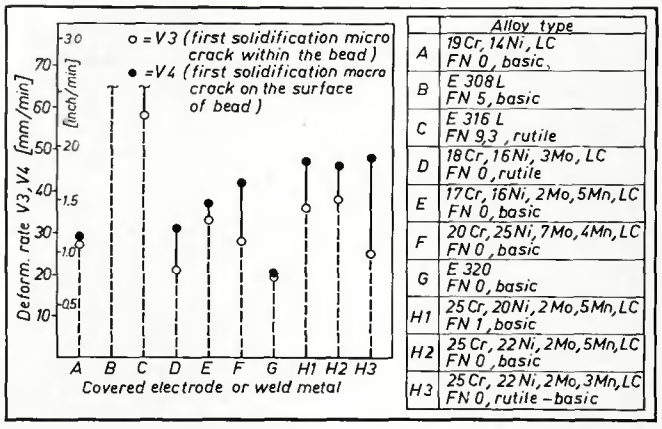
Electrode or weld metal	Alloy type	Total number of cracks in the transition zones over an entire length of 20 in. — Etching: 2p · HCl, 1p · HNO_3, 1p · H_2O_2[a]: Before bending	After bending	Fluorescence crack testing: Before bending	After bending
A	19Cr,14Ni,LC FN0,basic	18	79	13	92
B	E 308L VN5,basic	0	0	0	0
C	E 316L FN 9,3,rutile	0	0	–	–
D	18Cr,16Ni,3Mo,LC FN0,rutile	45	95	33	96
E	17Cr,16Ni,2Mo,5Mn,LC FN0,basic	9	30	–	–
F	20Cr,25Ni,7Mo,4Mn,LC FN0,basic	0	1	–	–
G	E 320 FN0,basic	23	77	22	82
H1	25Cr,20Ni,2Mo,5Mn,LC FN 1,basic	3	17	–	–
H2	25Cr,22Ni,2Mo,5Mn,LC FN0,basic	40	101	–	–
H3	25Cr,22Ni,2Mo,3Mn,LC FN0,rutile-basic	11	48	–	–

[a]Determination of cracks with magnification of ×40.



	Alloy type
A	19 Cr, 14 Ni, LC FN 0, basic
B	E 308 L FN 5, basic
C	E 316 L FN 9,3, rutile
D	18 Cr, 16 Ni, 3 Mo, LC FN 0, rutile
E	17 Cr, 16 Ni, 2 Mo, 5 Mn, LC FN 0, basic
F	20 Cr, 25 Ni, 7 Mo, 4 Mn, LC FN 0, basic
G	E 320 FN 0, basic
H1	25 Cr, 20 Ni, 2 Mo, 5 Mn, LC FN 1, basic
H2	25 Cr, 22 Ni, 2 Mo, 5 Mn, LC FN 0, basic
H3	25 Cr, 22 Ni, 2 Mo, 3 Mn, LC FN 0, rutile-basic

Fig. 10 – PVR test: critical deformation rates V1 and V3 in relation to weld metal alloy and type of covering



	Alloy type
A	19 Cr, 14 Ni, LC FN 0, basic
B	E 308 L FN 5, basic
C	E 316 L FN 9,3, rutile
D	18 Cr, 16 Ni, 3 Mo, LC FN 0, rutile
E	17 Cr, 16 Ni, 2 Mo, 5 Mn, LC FN 0, basic
F	20 Cr, 25 Ni, 7 Mo, 4 Mn, LC FN 0, basic
G	E 320 FN 0, basic
H1	25 Cr, 20 Ni, 2 Mo, 5 Mn, LC FN 1, basic
H2	25 Cr, 22 Ni, 2 Mo, 5 Mn, LC FN 0, basic
H3	25 Cr, 22 Ni, 2 Mo, 3 Mn, LC FN 0, rutile-basic

Fig. 11 – PVR test: critical deformation rates V3 and V4 in relation to weld metal alloy and type of covering

ferrite content measured corresponds quite well with that calculated according to DeLong.

Test Results

The test results and their evaluation appear on Tables 2 and 3 and in Figs. 10-14.

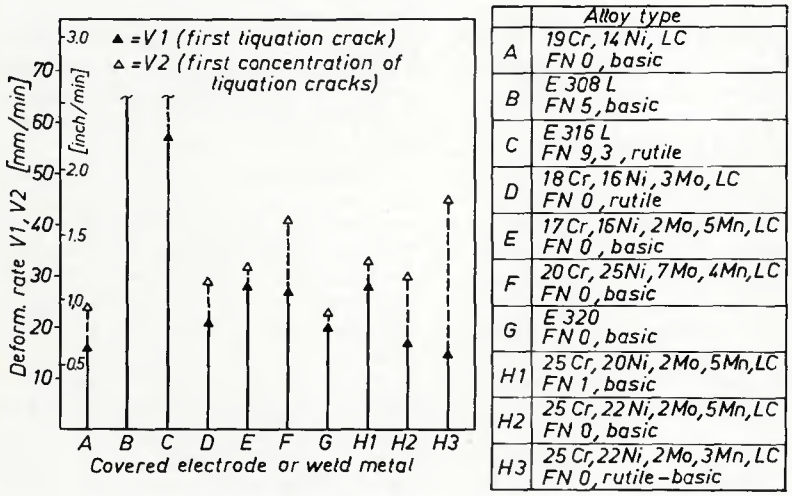
In general, it may be stated that the security against solidification and liquation cracks increases as the values for the corresponding critical deformation rates in the PVR test (Table 2) increase. This means that with high PVR values, the critical wall thicknesses also become larger in practical welding operations for the type of hot cracks observed each time to occur initially.

When comparing the fully austenitic test alloy A of the PVR test (Table 2) at room temperature with ferrite-containing test alloy B, which differs only by its 3.5% lower Ni content, great differences may be observed in the hot cracking behavior. Already at a V1 deformation rate of 16 mm/min (0.63 ipm), the first liquation cracks occur; these strongly increase in frequency at 24 mm/min (0.93 ipm) (V2). At 27 mm/min (1.06 ipm), the first microsolidification cracks (V3) could be observed. At deformation ranges between 20–30 mm/min (0.79–1.18 ipm) the PVR tensile test specimen is already ruptured. Up to an approximate deformation rate of 70 mm/min (2.76 ipm), test alloy B shows neither liquation nor solidification cracks. This comparison gives an impression of how great an effect the primary solidification and/or residual delta-ferrite content can have on the hot cracking sensitivity.

Weld metal C with a delta-ferrite content of 9.3 FN as in commercial electrode type AWS E 316 L-16, behaves similarly to alloy B, which corresponds to electrode type AWS E 308 L-15. Only 4 liquation cracks were discovered by means of the PVR test at deformation rates between 50 and 60 mm/min (1.97 and 2.36 ipm). This yields a very high critical deformation rate V1 of 57 mm/min (2.24 ipm).

When comparing fully austenitic weld metal alloys D and E, additional basic findings result. The fully austenitic weld metal of rutile covered electrode D differs from the fully austenitic weld metal of basic covered electrode E in the chemical composition because of essentially differing Mn and Si contents. Based on past experience, alloy D with lower Mn and higher Si contents is essentially more susceptible to cracking than alloy E. As may be noted from the results of the PVR test, V1 is 21 mm/min (0.83 ipm) compared to 28 mm/min (1.10 ipm) in alloy E. Moreover, critical deformation rate V2 for the first accumulation of liquation cracks in alloy D is lower than in alloy E. Also with regard to susceptibility to solidification cracks, essential differences exist. V3 for instance is 21 mm/min (0.83 ipm) for alloy D, while for alloy E it is 33 mm/min (1.30 ipm).

Similar results to those for alloys D and E are obtained, although in an even more distinct form, when comparing essentially higher alloyed weld metals F and G (type AWS E 320-15). Both types are basic electrodes. The high Mn and Mo content has a very favorable effect on the hot



	Alloy type
A	19 Cr, 14 Ni, LC FN 0, basic
B	E 308 L FN 5, basic
C	E 316 L FN 9,3, rutile
D	18 Cr, 16 Ni, 3 Mo, LC FN 0, rutile
E	17 Cr, 16 Ni, 2 Mo, 5 Mn, LC FN 0, basic
F	20 Cr, 25 Ni, 7 Mo, 4 Mn, LC FN 0, basic
G	E 320 FN 0, basic
H1	25 Cr, 20 Ni, 2 Mo, 5 Mn, LC FN 1, basic
H2	25 Cr, 22 Ni, 2 Mo, 5 Mn, LC FN 0, basic
H3	25 Cr, 22 Ni, 2 Mo, 3 Mn, LC FN 0, rutile-basic

Fig. 12 – PVR test: critical deformation rates V1 and V2 in relation to weld metal alloy and type of covering

	Alloy type	
H1	25 Cr, 20 Ni, 2 Mo, 5 Mn, LC	FN 1, basic
H2	25 Cr, 22 Ni, 2 Mo, 5 Mn, LC	FN 0, basic
H3	25 Cr, 22 Ni, 2 Mo, 3 Mn, LC	FN 0, rutile-basic

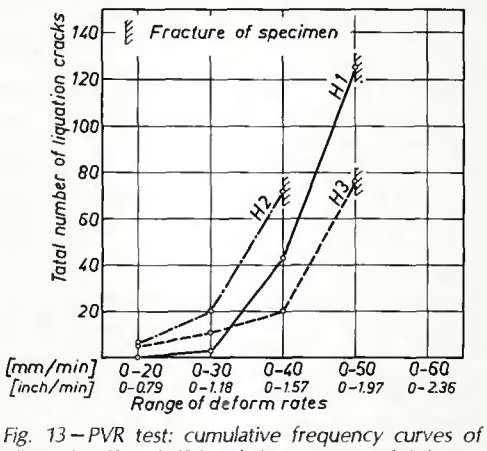
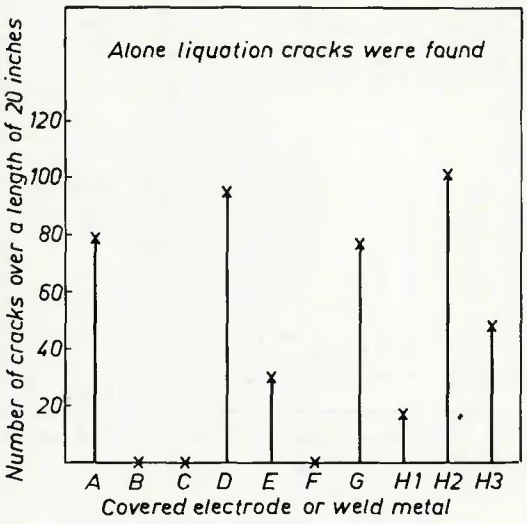


Fig. 13 – PVR test: cumulative frequency curves of alloys H1, H2 and H3 in relation to range of deformation rates



	Alloy type
A	19 Cr, 14 Ni, LC FN 0, basic
B	E 308 L FN 5, basic
C	E 316 L FN 9,3, rutile
D	18 Cr, 16 Ni, 3 Mo, LC FN 0, rutile
E	17 Cr, 16 Ni, 2 Mo, 5 Mn, LC FN 0, basic
F	20 Cr, 25 Ni, 7 Mo, 4 Mn, LC FN 0, basic
G	E 320 FN 0, basic
H1	25 Cr, 20 Ni, 2 Mo, 5 Mn, LC FN 1, basic
H2	25 Cr, 22 Ni, 2 Mo, 5 Mn, LC FN 0, basic
H3	25 Cr, 22 Ni, 2 Mo, 3 Mn, LC FN 0, rutile–basic

Fig. 14—Fissure bend test: Relation of number of cracks to the weld metal alloy and type of covering

cracking resistance of alloy F. For alloy G, the negative effect of niobium on the hot cracking resistance in fully austenitic weld metal must also be taken into account.

Quite interesting is the different hot cracking behavior of slightly differing alloys H1 and H2, used today for urea plants. At room temperature, alloy H1 presents above all very low residual delta-ferrite of 0 to 1 FN because of its lower Ni content. However, it is precisely these small ferrite parts that greatly increase the resistance against liquation cracks. In the PVR test, critical deformation rate V1 amounts to 28 mm/min (1.10 ipm) for the first liquation cracks to occur in alloy H1; in H2 this is only 17 mm/min (0.67 ipm). Critical deformation rate V2 is also higher for alloy H1.

Although such a great behavioral difference exists in relation to liquation cracks, critical deformation rates V3 and V4 are relatively high and almost the same for solidification crack formation in the PVR-test. This means that a very small delta ferrite content increases the resistance against liquation cracks quite well; however, it still does not influence the susceptibility to solidification cracks.

Electrode H3, also interesting in urea installation construction, is a mixed electrode type as compared to H2. The weld metal of H3 contains only about 3% Mn in comparison to about 5.4% Mn for the H2 alloy. In this connection, it is remarkable that in the PVR test the fully austenitic alloy of mixed electrode type H3 shows a very low critical deformation rate V1 while, on the other hand, V2 is very high as a criterion for increased accumulation of liquation cracks. This means that liquation cracks occur with relatively small deformations; however, those cracks take on a greater magnitude only at relatively great deformations. In order for a micro-solidification crack to occur for the first time, critical deformation rate V3 is lower for alloy H3 than for alloys H1 and H2.

With deformation conditions according to the fissure bend test (Table 3), the only liquation cracks (when any were found) were in the heat-affected zones of the single beads. Analysis of the number of cracks found in the bent specimen shows that they correspond very well when etched with 2 parts HCl, 1 part HNO_3 and 1 part H_2O_2 when using the fluorescence penetration test. However, before bending, less cracks are found with the last mentioned method. Based on the liquation cracks counted, the fissure bend test also provides a good classification of the individual weld electrodes and/or metals. But this is only valid for deformations occurring using this testing method.

Conclusions from the Test Results

It was demonstrated that by means of the newly developed PVR test, the limit values of the deformability of a weld metal alloy can be well detected at the cooling and re-liquation cycles of the welding process. It is thereby possible to distinguish on one and the same PVR test, between the first appearance and accumulation of liquation cracks as well as the first appearance of micro and macro-solidification cracks. The definition of 4 different critical deformation rates has proven itself as a criterion for the quantitative analysis in relation to the susceptibility to hot cracking. Practical correlations can be established, if one succeeds in determining the corresponding critical plate thicknesses for the same material, using the critical deformation rates of the PVR test.

Weld metal alloy test results, using the PVR test, clearly show that a certain delta-ferrite content in the austenitic weld metal structure is the best way to avoid solidification and liquation cracks (alloys B and C in Fig. 10). This is especially valid if no special measures are taken with regard to the increase of Mn and Mo content with lowest possible Si content. If hot cracks occur in fully austenitic weld metal alloys, they are generally first found in the form of liquation cracks.

Liquation cracks always appear only as micro-cracks. On the other hand, solidification cracks very quickly take on such a magnitude at increasing deformation that they can constitute a serious danger for the safety of the weldment. Therefore, macro-solidification cracks should be avoided by means of a corresponding delta-ferrite content and/or through appropriate alloying measures in fully austenitic weld metal. Figure 11 clearly shows how sensitive the individually tested alloys are in relation to the formation of solidification cracks. Because of the reasons explained above, fully austenitic alloys A, D and G very quickly reach the critical deformation range of micro- and macro-solidification cracks. Consequently, when welding these alloys, special care should be taken.

All high-alloy fully austenitic weld metals E, F, H1 and H2 with high Mn content of 4.3% to 5.5% and with Mo content over 7% and low Si-content show higher critical deformation rates. They are, therefore, less susceptible to solidification cracks. As for the appearance of macro-solidification cracks, alloy H3 of mixed electrode type H3 with a 3% Mn content, although favorable, does show micro solidification cracks relatively soon.

Liquation cracks normally have a length of 0.05–0.3 mm (0.002–0.012 in.). Size-wise they are certainly much less critical than the macro-solidification cracks mentioned before. The question is, however, at what accumulation such cracks lead to material failure, such as during urea synthesis, e.g., where special corrosion conditions exist. When evaluating the PVR test, it was, therefore, significant to determine for critical deformation rate V1 when the first liquation cracks appeared, while determining for critical deformation rate V2 the accumulation of these cracks. To reduce the number of liquation cracks, the same preventive measures as for avoiding solidification cracks are basically useful. This is shown in Fig. 12.

Comparison of alloys H1 and H2 (Fig. 12) shows that even the lowest delta ferrite content ranging between 0 to 1 FN has a very positive effect on the resistance against liquation cracks. On the other hand, this low ferrite content has no appreciable positive effect on the sensitivity to solidification cracking. Of further importance, the critical deformation rate V2 in the PVR test is shifted to the highest possible values for the first accumulation of liquation cracks. Compared to the weld metals of electrodes H1 and H2, the weld metal of H3 meets this requirement—Figs. 12 and 13.

Figure 13 shows the total number of liquation cracks covering the different deformation ranges of weld metal alloys H1, H2 and H3. Comparison of the curves clearly shows the different hot cracking behavior of the entire deformation range possible.

The research has demonstrated that the newly developed PVR test is very useful for accurate characterization of a material with regard to its tendency to solidification and liquation crack formation. Therefore, the PVR test is a valuable aid for the development of new high corrosion resistant filler metals, especially in the field of fully austenitic structures.

As already mentioned, the fissure bend test also enables a certain classification of weld metal alloys insofar as liquation cracks are concerned. This is shown in the diagram of Fig. 14. But with this test method, it is not possible to differentiate between the first appearance and the accumulation of liquation cracks and the first occurrence of micro- and macro-solidification cracks.

Conclusion

Today, fully austenitic filler metals are used for reasons of maximum corrosion resistance, high cryogenic ductility and non-magnetizability. However, fully austenitic weld metal is susceptible to hot cracking, whereby a distinction must be made between solidification and liquation hot-cracking.

The present paper demonstrates how it is possible to determine by means of a newly developed hot cracking test method – the PVR test – the deformability limits of a weld metal in relation to the formation of solidification and liquation cracks. For this purpose, four critical deformation rates were defined, by which means at least an approximate correlation to the behavior in actual weldments could be established.

Suitable alloying measures used with primary austenitic solidifying weld metal alloys, which are fully austenitic also at room temperature, can go a long way in avoiding solidification cracks. But it is very difficult to completely avoid microscopically fine liquation cracks in rigid and highly restrained structures. On the other hand, it is possible to influence their accumulation at given conditions through suitable alloying measures or through adaptation of the covering type. Elevated Mn and Mo contents in comparison to low Si and Nb contents have an advantageous effect on the resistance of fully austenitic weld metal vis-à-vis hot cracking in general and liquation cracking in particular. Here, however, the absolute total alloy content of the weld metal plays a role.

Even the lowest delta-ferrite content of 0 to 1 FN has a very positive effect on the resistance to liquation cracks. However, these are ferrite contents that still have no effect on the sensitivity to solidification cracking.

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American Welding Society, Inc.

Report on Financial Statements

Year Ended May 31, 1982

Board of Directors
American Welding Society, Inc.

We have examined the balance sheet of American Welding Society, Inc., as of May 31, 1982 and the related statements of revenue and expense, changes in fund balances and changes in financial position for the year then ended. Our examination was made in accordance with generally accepted auditing standards and, accordingly, included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the financial statements mentioned present fairly the financial position of American Welding Society, Inc., at May 31, 1982 and the results of its operations, changes in its fund balances and changes in financial position for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the prior year.

SEIDMAN & SEIDMAN
Certified Public Accountants

Miami, Florida
October 15, 1982

AMERICAN WELDING SOCIETY, INC.
BALANCE SHEET
MAY 31, 1982
With Comparative Totals for 1981

	Operating Fund	Reserve Fund	Awards Fund	Safety and Health Fund	Interfund Elimina-tions	Total 1982	Total 1981
ASSETS							
CURRENT:							
Cash and cash equivalents including certificate of deposit of $66,000	$ 130 028	$332 287	$82 651	$ 54 014		$ 598 980	$ 373 660
Short-term investments							24 875
Accounts receivable, less allowance of $84,385	263 748					263 748	275 335
Current portion of mortgage receivable (Note 4)	146 205					146 205	
Inventories	280 121					280 121	278 474
Due from operating fund		225 086		61 024	$(286 110)		
Other (Note 1)	210 857					210 857	162 959
TOTAL CURRENT ASSETS	1 030 959	557 373	82 651	115 038	(286 110)	1 499 911	1 115 303
PROPERTY AND EQUIPMENT (Notes 2, 3 and 5), less accumulated depreciation	2 315 821					2 315 821	2 610 482
OTHER:							
Investment in bonds, at market		40 532				40 532	38 340
Mortgage receivable (Note 4)	337 497					337 497	
Refundable deposits	11 887					11 887	12 149
	$3 696 164	$597 905	$82 651	$115 038	$(286 110)	$4 205 648	$3 776 274
LIABILITIES AND FUND BALANCE							
CURRENT LIABILITIES:							$ 36 122
Checks issued against future deposits						$ 351 520	430 877
Accounts payable and accrued expenses	$ 350 551	$ 969					
Current maturities of long-term debt (Notes 3 and 5)	285 001					285 001	533 107
Deferred membership and subscription income	388 091					388 091	331 159
Due to other funds	282 581		$ 3 529		$(286 110)		
TOTAL CURRENT LIABILITIES	1 306 224	969	3 529		(286 110)	1 024 612	1 331 265
OTHER:							
Long-term debt, less current maturities (Note 5)	1 261 342					1 261 342	1 504 648
Obligation under capital leases (Note 3)	21 756					21 756	45 708
Customer deposits	14 944					14 944	19 057
TOTAL LIABILITIES	2 604 266	969	3 529		(286 110)	2 322 654	2 900 678
DEFERRED REVENUE (Note 6)			79 122	$115 038		194 160	211 161
FUND BALANCE	1 091 898	596 936				1 688 834	664 435
	$3 696 164	$597 905	$82 651	$115 038	$(286 110)	$4 205 648	$3 776 274

See accompanying summary of accounting policies and notes to financial statements.

AMERICAN WELDING SOCIETY, INC.
STATEMENT OF REVENUE AND EXPENSE
for the year ended May 31, 1982
With Comparative Totals for 1981

	Revenue	Direct Expense	Excess (Deficiency) of Revenue Over Expense 1982	1981
OPERATING FUND				
ACTIVITIES:				
Membership	$1 271 210	$ 485 950	$ 785 260	$ 591 584
Convention	1 269 674	570 131	699 543	397 460
Technical	1 070 853	731 535	339 318	169 978
Qualification and Certification	285 678	205 239	80 439	55 734
Education	451 843	496 736	(44 893)	18 200
IIW	32 629	17 454	15 175	10 198
Communication	1 105	68 625	(67 520)	(94 766)
Welding Journal	869 205	967 546	(98 341)	(107 153)
Building operations	120 547	197 488	(76 941)	(157 875)
Administrative	16 628	1 358 705	(1 342 077)	(1 248 454)
Gain on sale of property	576 073	—	576 073	—
Interest income	119 665	—	119 665	—
	$6 085 110	$5 099 409	985 701	(365 094)
RESERVE FUND				
INTEREST INCOME	$ 36 391			
GAIN ON INVESTMENTS	115			
	$ 36 506		36 506	50 551
AWARDS FUND				
INTEREST INCOME (Note 6)	$ 3 360			
AWARDS EXPENSES (Note 6)		$ 3 360		
	$ 3 360	$ 3 360		
SAFETY AND HEALTH FUND				
DONATIONS (Note 6)	$ 59 005			
INTEREST (Note 6)	3 685			
RESEARCH PROGRAM EXPENSES (Note 6)		$ 62 690		
	$ 62 690	$ 62 690		
EXCESS (DEFICIENCY) OF REVENUE OVER EXPENSE			$1 022 207	$(314 543)

See accompanying summary of accounting policies and notes to financial statements.

AMERICAN WELDING SOCIETY, INC.
STATEMENT OF CHANGES IN FUND BALANCES
for the year ended May 31, 1982
With Comparative Totals for 1981

	Operating Fund	*Reserve Fund*	*Total* 1982	*Total* 1981
BALANCES, at beginning of year	$ 106 197	$558 238	$ 664 435	$ 984 031
ADD—Excess (deficiency) of revenue over expense	985 701	36 506	1 022 207	(314 543)
ADD (DEDUCT)—Adjustments to reflect non-current investments at market		2 192	2 192	(5 053)
BALANCES, at end of year	$1 091 898	$596 936	$1 688 834	$ 664 435

See accompanying summary of accounting policies and notes to financial statements.

AMERICAN WELDING SOCIETY, INC.
STATEMENT OF CHANGES IN FINANCIAL POSITION
for the year ended May 31, 1982
With Comparative Totals for 1981

	Operating Fund	*Reserve Fund*	*Awards Fund*	*Safety and Health Fund*	*Interfund Elimina-tions*	*Total* 1982	*Total* 1981
SOURCE OF WORKING CAPITAL:							
Excess (deficiency) of revenue over expense	$ 985 701	$ 36 506				$1 022 207	$ (314 543)
Add (deduct) items not requiring (providing) working capital:							
Depreciation	157 464					157 464	138 814
Change in deferred revenue			$4 454	$(21 455)		(17 001)	(18 859)
Amortization of discount on mortgage receivable	(2 443)					(2 443)	
Total provided from (absorbed by) operations	1 140 722	36 506	4 454	(21 455)		1 160 227	(194 588)
Reduction in mortgage receivable	550 983					550 983	
Book value of property sold	334 463					334 463	
Additions to long-term debt	15 600					15 600	2 137 791
(Increase) decrease in long-term investments		(2 192)				(2 192)	29 928
Decrease in due from other funds (non-current portion)		150 362			$(150 362)		
Increase in customer deposits and other liabilities							19 784
Increase in deferred revenues							6 616
Unrealized gain (loss) on long-term investments		2 192				2 192	(5 053)
Total	2 041 768	186 868	4 454	(21 455)	(150 362)	2 061 273	1 994 478
USE OF WORKING CAPITAL:							
Increase in mortgage receivable	886 037					886 037	
Reductions of long-term debt	282 858					282 858	587 435
Additions to property and equipment	197 266					197 266	2 147 071
Decrease in other-net	3 851					3 851	
Total	1 370 012					1 370 012	2 734 506
INCREASE (DECREASE) IN WORKING CAPITAL	$ 671 756	$ 186 868	$4 454	$(21 455)	$(150 362)	$ 691 261	$ (740 028)

See accompanying summary of accounting policies and notes to financial statements.

AMERICAN WELDING SOCIETY, INC.
STATEMENT OF CHANGES IN FINANCIAL POSITION
(continued)
for the year ended May 31, 1982
With Comparative Totals for 1981

	Operating Fund	*Reserve Fund*	*Awards Fund*	*Safety and Health Fund*	*Interfund Elimina-tions*	*Total* 1982	*Total* 1981
CHANGES IN WORKING CAPITAL ITEMS:							
Increase (decrease) in current assets:							
Cash and cash equivalents	$ 166 150	$ 65 187	$ 9 241	$ 20 864		$ 261 442	$ 5 608
Short-term investments		(24 875)				(24 875)	24 875
Accounts receivable	(10 229)		(1 358)			(11 587)	(65 333)
Current portion of mortgage receivable	146 205					146 205	
Inventories	1 647					1 647	(44 752)
Other	47 898					47 898	110 145
Due from other funds		147 525		(42 319)	$(105 206)		
Total	351 671	187 837	7 883	(21 455)	(105 206)	420 730	30 543
Decrease (increase) in current liabilities:							
Checks issued against future deposits							5 400
Current maturities of long-term debt	248 106					248 106	(533 107)
Accounts payable and accrued expenses	80 326	(969)				79 357	(221 387)
Deferred membership and subscription income	(56 932)					(56 932)	(21 477)
Due to other funds	48 585		(3 429)		(45 156)		
Total	320 085	(969)	(3 429)		(45 156)	270 531	(770 571)
INCREASE (DECREASE) IN WORKING CAPITAL	$ 671 756	$ 186 868	$ 4 454	$(21 455)	$(150 362)	$ 691 261	$(740 028)

See accompanying summary of accounting policies and notes to financial statements.

AMERICAN WELDING SOCIETY, INC.
SUMMARY OF ACCOUNTING POLICIES

DESCRIPTION OF BUSINESS

The American Welding Society, Inc., is a not-for-profit, technical society, exempt from income tax under Section 501 (c)(3) of the Internal Revenue Code. However, certain publications advertising revenue and rental income, considered unrelated business income (none in the current year), are taxable to the Society for income tax purposes.

FUND ACCOUNTING

The Society has four funds, which are described as follows:

Operating Fund—This fund is used to account for all resources over which the Society has discretionary control, except for those unrestricted resources accounted for in the Reserve Fund.

Reserve Fund—This fund is used to account for Board designated reserve funds which are to be used to supplement the cash needs of the Operating Fund.

Awards Fund—This restricted fund is used to account for cash donated to the Society to finance awards for contributions to welding technology.

Safety and Health Fund—This restricted fund is used to account for cash donated to the Society to fund research programs for the study of various environments to which welders may be exposed.

INVENTORIES

Inventories of publications are valued at the lower of cost or market. Cost is determined by the weighted average method.

PROPERTY, EQUIPMENT AND DEPRECIATION

Property and equipment are stated at cost. Expenditures for additions, renewals and betterments are capitalized; expenditures for maintenance and repairs are charged to expenses as incurred. Upon retirement or disposal of assets, the cost and accumulated depreciation are eliminated from the accounts and the resulting gain or loss is included in income. Depreciation is computed using the straight line method over the following estimated useful lives:

	Years
Buildings and improvements	14–20
Office furniture and equipment	5–7
Transportation equipment	3

REVENUE RECOGNITION

Welding show revenues and expenses are recognized in the year that the show to which they relate is held.

Membership and subscription revenues in the Operating Fund are deferred when received and recognized as revenue when earned, substantially in the subsequent year.

Donations, restricted as to use, and related investment income are deferred when received, and recognized as revenue when specific restrictions are met.

AMERICAN WELDING SOCIETY, INC.
NOTES TO FINANCIAL STATEMENTS

NOTE 1—OTHER CURRENT ASSETS

Included in other current assets is $100,000 due on a fidelity bond resulting from a defalcation in the prior year. The amount of the loss has been determined to be approximately $115,000. Under certain circumstances the additional $15,000 may be recoverable which will be recorded at the time such recoverability becomes known. After year end, $100,000 was collected from the bonding company.

In addition, the Society advanced $50,000 to its new Executive Director to assist him with moving expenses. This amount has been collected subsequent to year end.

NOTE 2—PROPERTY AND EQUIPMENT

Major classes of property and equipment consist of the following:

Land	$ 720 000
Building and improvements	1 482 364
Office furniture and equipment	527 013
Transportation equipment	7 273
	2 736 650
Less accumulated depreciation and amortization	420 829
Net property and equipment	$2 315 821

Land, building and building improvements with a net carrying amount of $2,071,010 are pledged as collateral on certain long-term debt (Note 5).

NOTE 3—CAPITALIZED LEASES

The Society leases its data processing equipment under terms requiring the classification as a capital lease. Amounts capitalized during the year ended May 31, 1982 were $15,567, and amortization for the current period totalled $12,389.

The following is a schedule by years of future minimum lease payments:

1983	$ 43 519
1984	21 789
Total minimum lease payments	65 308
Less amount representing interest, calculated at the Society's incremental borrowing rate	4 613
Present value of minimum lease payments	60 695
Less current maturities	38 939
Obligation under capital leases	$ 21 756

NOTE 4—MORTGAGE RECEIVABLE

During the current year, the Society sold certain land and buildings for approximately $1,100,000. The Society received approximately $13,000 in cash (net of $87,000 expenses of sale) and a purchase money mortgage in the amount of $1,000,000.

The mortgage is payable in monthly installments of $50,000 plus interest through August 1982. Commencing in August, 1983, eight annual interest only payments are due with the balance of $400,000 together with any unpaid interest due in August, 1991. This mortgage receivable has been pledged as collateral for the note payable, bank (Note 5).

The outstanding balance at May 31, 1982 consists of the following:	
12% purchase money mortgage	$ 550 000
Less unamortized discount at an imputed interest rate of 15.25%	66 298
	483 702
Less current maturities	146 205
Total mortgage receivable (noncurrent)	$ 337 497

NOTE 5—LONG-TERM DEBT

Long-term debt at May 31, 1982 consists of the following:	
Note payable, bank, payable in monthly installments of $50,000 plus interest at 1% over prime with a final payment of $28,000 due in September, 1982	$ 178 000
8½%, first mortgage, payable in monthly installments of $7,690, including principal and interest, with a final balloon payment of $781,315 due in August, 1988	904 661
8½%, second mortgage, payable in monthly installments of $3,116, including principal and interest, to August, 1988	179 478
11%, purchase money mortgage, payable in monthly installments of $4,540, including principal and interest, to August, 1988	245 265
Total	1 507 404
Less current maturities	246 062
Total long-term debt	$1 261 342

NOTE 6—DEFERRED REVENUE

The following schedule summarizes the activity in the individual deferred revenue accounts from June 1, 1981 to May 31, 1982:

	Awards Fund	Safety and Health Fund
Deferred revenue June 1, 1981	$74 668	$136 493
Contributions received for the year ended May 31, 1982		37 550
Interest earned on restricted funds	7 814	3 685
Disbursements in accordance with donor restrictions, amortized to income	(3 360)	(62 690)
Deferred revenue, May 31, 1982	$ 79 122	$ 115 038

NOTE 7—SUBSEQUENT EVENT

Subsequent to May 31, 1982, the Society arranged with a bank for a line of credit agreement with a limit of $200,000. Interest will be charged at prime rate plus 1% on outstanding balances. As of the report date, no amounts had been drawn on the line of credit.