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National Aeronautics and
Space Administration

Office of Management

Scientific and Technical
Information Program

Summary

An investigation was conducted to determine the cause of the failure of a massive AISI Type 316 stainless steel valve which controlled combustion air to a jet engine test facility. Several through-the-wall cracks were present near welded joints in the valve skirt. The valve had been in outdoor service for 18 years. Samples were taken in the cracked regions for metallographic and chemical analyses. Insulating material and sources of water mist in the vicinity of the failed valve were analyzed for chlorides. A scanning electron microscope was used to determine whether foreign elements were present in a crack. On the basis of the information generated, the failure was characterized as external stress-corrosion cracking. The cracking resulted from a combination of residual tensile stress from welding and the presence of aqueous chlorides. Recommended countermeasures are included.

Introduction

A detailed investigation was conducted on a progressive, localized failure in an AISI Type 316 stainless steel valve skirt. This 1.22-m-diameter by 15-mm-wall valve controlled the combustion air supply to a jet engine test facility which had been in operation at the NASA Lewis Research Center for 18 years. The failure was detected during a routine visual inspection of the internal surfaces of the combustion air line.

Three through-the-wall cracks were found in the valve skirt near welded joints which were made using the gas metal arc and the gas tungsten arc welding processes. One of these cracks was located in the heat-affected zone (HAZ) of a circumferential butt joint. The other two were toe cracks under support ring T-joints. The failure was not discovered audibly because the air supply line was located in an outdoor, noisy environment.

As the investigation progressed, many additional cracks were observed in the valve near both butt and T-joints. The objective of this investigation was to characterize the cracking problem so that the reasons for the failure could be understood. Countermeasures are offered and other suggestions are made to minimize the possibility of this kind of failure in the future.

Operation of Valve 1V–6

The outdoor pipeline immediately upstream and downstream from the failed 1V–6 valve is shown in figure 1. Valve 1V–6 is used in various modes to blend and divert combustion air to altitude test chambers in an adjacent building. These chambers are used in the testing of full-size aircraft turbine engines.

In one mode of operation, ambient combustion air is delivered to the test cell at a maximum delivery rate of 181 kg/sec at 1.14 MPa absolute (fig. 2). In another mode, ambient combustion air is blended with air chilled to −68 °C. This chilled air is discharged from valve AC4661 at 181 kg/sec at 0.17 MPa absolute. In a third mode, valve 1V–6 can be used to divert ambient combustion air through the J57 heat exchangers (where nonvitiated air can be heated to 400 °C). This heated air is then discharged through valve AC4663 and is mixed with ambient air. In the highest operating temperature variation of the third mode, valve 1V–6 is closed. As seen in figure 2, all of the combustion air is forced through the heat exchangers. The air temperature at the upstream face of valve 1V–6 is at about 27 °C and at the downstream face is from 340 to 370 °C. The high-temperature mode of operation was used in about 20 of the 100 annual runs made over the past 18 years. In a typical run, the time at the maximum operating temperature was about 3 hr, and the pressure on the upstream face of the valve (about 1.14 MPa abs) was only slightly higher than the pressure on the downstream face.

For the first 12 years of operation, valve 1V–6 was covered with an asbestos-mud insulating material. The mud was then removed, and during the last 6 years of operation 51-mm-thick aluminum foil-faced fiberglass blanket insulation was used.

Exterior Environment

Valve 1V–6 is often exposed to mist from an adjacent drain basin for cooling towers 3 and 6, which supply cooling water to the altitude test chambers. These towers are located about 100 m from valve 1V–6. Cooling towers 1, 2, and 4, are closer to 1V–6 than towers 3 and 6. However, nearly all

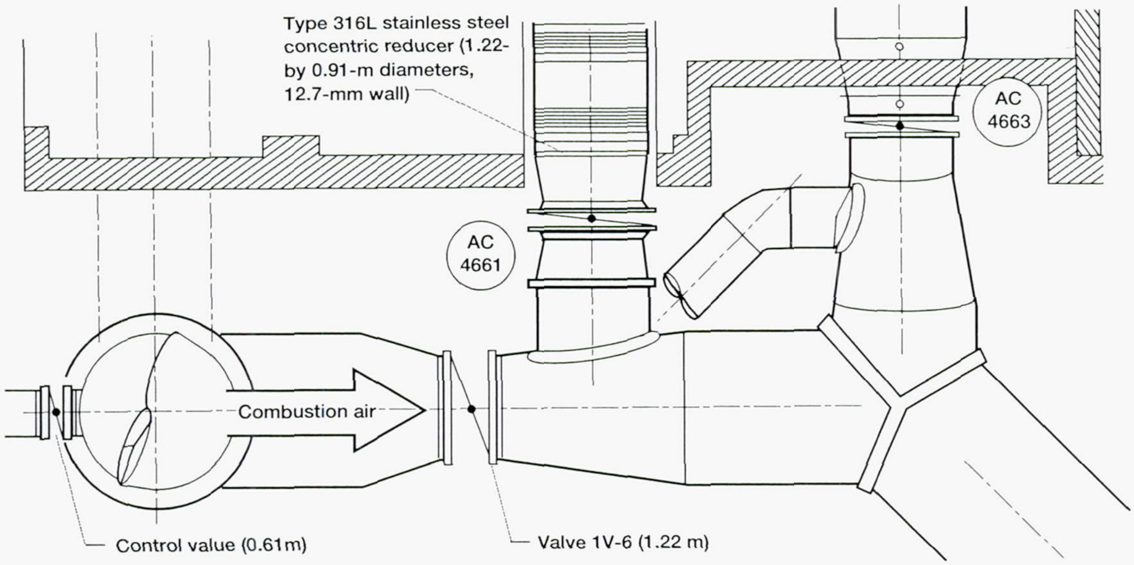


Figure 1.—A portion of the plan drawing of the outdoor air supply system. Cracking occurred at valve 1V-6.

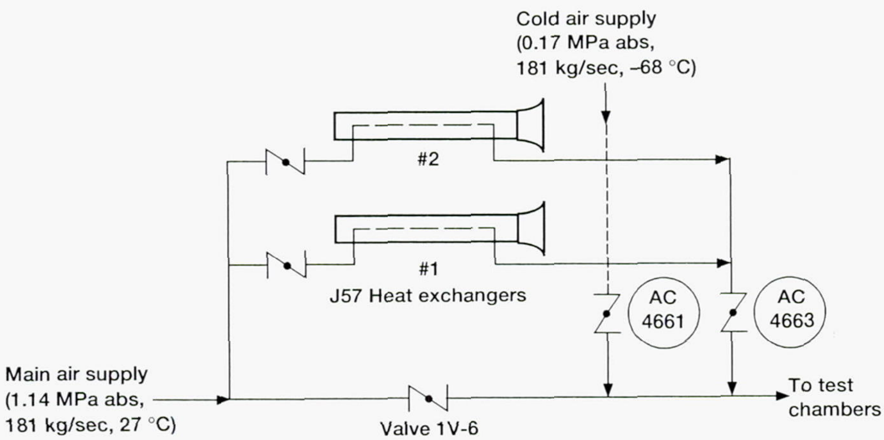


Figure 2.—Piping for the combustion air supply system.

the mist in the vicinity of valve 1V–6 is generated by the splashing water as it is discharged into the drain basin. The towers per se may provide a small amount of the mist depending on the wind direction and drift.

From the outset of this investigation, stress-corrosion cracking (SCC) was suspected as the possible failure mechanism. For this reason, environmental sources of chlorides, including the Cleveland city water used in the cooling towers, were considered. This water contains 20 to 40 ppm chlorides. During normal operation, the chloride concentration in the large cooling tower water systems generally increases to 40 to 80 ppm because of water evaporation.

Prior to 1969, other sources of chlorides were the chemicals used to treat the cooling tower water. Sodium chromate and sodium phosphate were used for corrosion control and sulfuric acid for pH control. Then, in 1969 the water treatment procedures were changed because these materials were environmentally unsafe, having toxic effects on aquatic life. The new chemicals used were nonchromate, organo-zinc lignosulfonates coupled with chelating agents. Also, the usage of water softeners in cooling towers 3 and 6 was stopped at this time.

After 1969, biocide additions to the cooling tower water were used to control the buildup of algae and slime in the towers. These biocides are quaternary ammonium chlorides with organo-tin complexes. In the mid-1970's, although the corrosion inhibitors were changed to zinc phosphate compounds, the usage of biocide chemicals continued until 1988 when a pair of new and different biocide materials were introduced. One product, a solid material containing trichloro-s-triazinetrione and sodium bromide, slowly releases chlorine into the water. The other product, used alternately, is a liquid that contains dodecylguanidine hydrochloride and methylene bis(thiocyanate). All of these biocides contribute chlorides to the cooling tower water.

The final source of chlorides at the outer surface of valve 1V–6 is a hydraulic fluid, which is present at the linear actuator for valve 1V–6. This oily fluid contains 5 to 10 ppm chlorides.

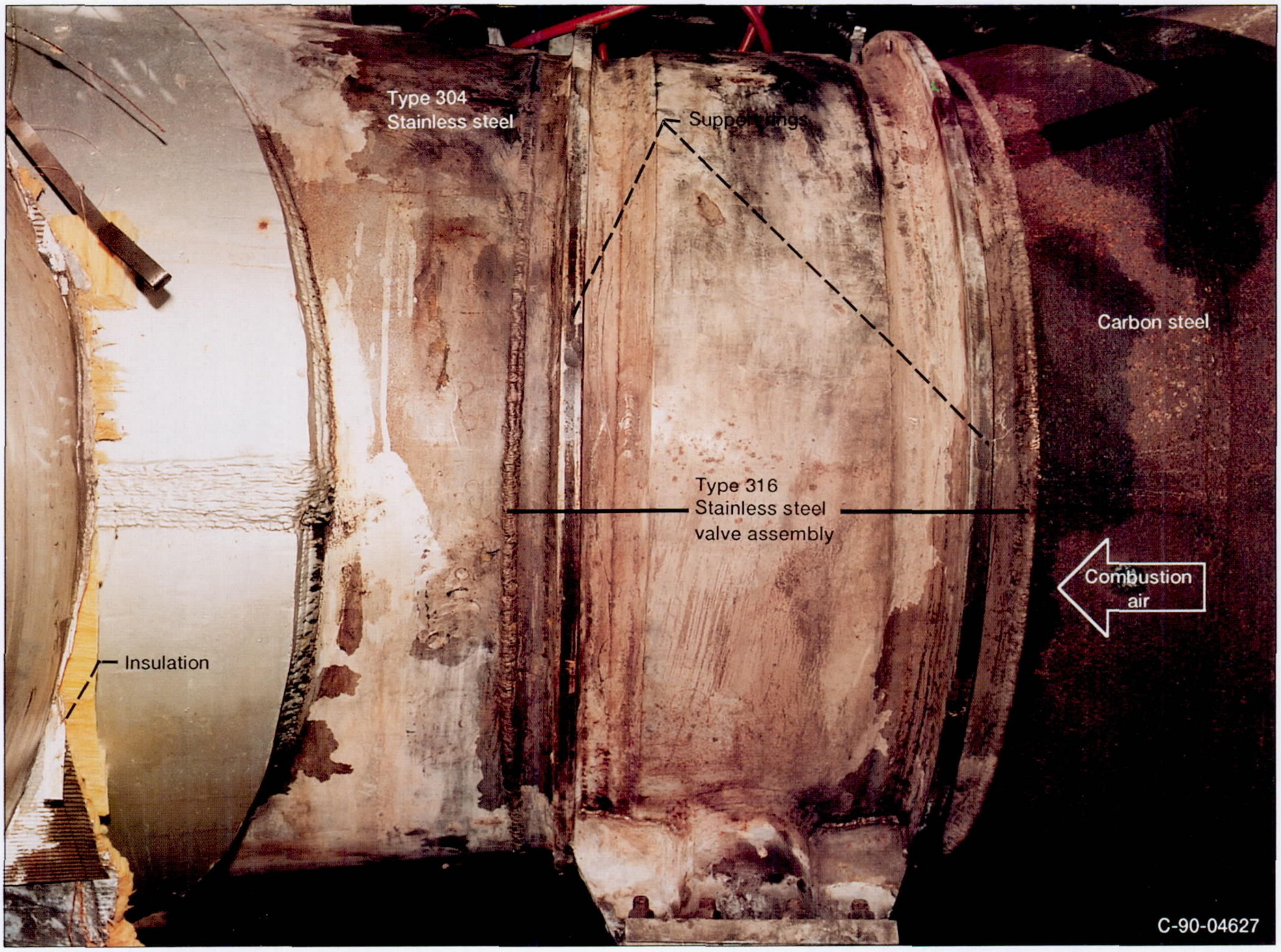


Figure 3.—Valve 1V-6 (1.22-m diam) with insulation removed showing dual support rings welded to the valve skirt.

Procedure

The 1.22-m-diameter by 15-mm-wall Type 316 stainless steel valve 1V–6 is shown in figure 3 with the fiberglass insulation removed. The carbon steel air inlet pipe and the Type 304 stainless steel outlet pipe are also shown. Support rings (25.4 mm wide by 51 mm high) were welded to the skirt in T-joints on both the upstream and downstream sides of the butterfly valve. The metallographic failure investigation was concentrated primarily at the downstream side of the valve where dye penetrant inspection first revealed two through-the-wall cracks in the valve skirt. Later in the investigation, other cracks, including a through-the-wall crack, were discovered at the upstream side of the valve. Although these latter cracks were characterized, the photomicrographs are not presented herein.

An internal view of the valve in the open position (looking upstream) is shown in figure 4. An identical view in the closed position is shown in figure 5. Through-the-wall cracking was present in the weld HAZ for about half the circumference of the butt joint on the south and north sides. Figure 5 also shows the locations from which 21-mm-diameter metallographic plug samples W, X, and Y were taken from the butt joint and the region from which sample Z was taken from the T-joint. Figures 6 and 7 are external views showing the plug holes, which were centered at the butt joint cracks. The plugs included weld metal, HAZ, and unaffected base metal. Figure 6 also shows that the area of sample Z (which was cut out later) included a portion of the support ring. The internal view in figure 8 shows the plug holes of samples X and W and a portion of the through-the-wall toe crack from the external ring-to-skirt T-joint. This toe crack, which was evident along the inner circumference, was parallel to the circumferential butt joint crack. These cracks were only about 25 mm apart. Sample Z (shown in fig. 9), which contains the toe crack, was obtained by manual plasma arc cutting. The downstream support ring was included with a 10- by 26-cm portion of the skirt. Cross sections of sample Z were taken transverse to the support ring for both macro- and micro-examination.

Figure 4.—Internal view (looking upstream) of valve 1V-6 in the open position.

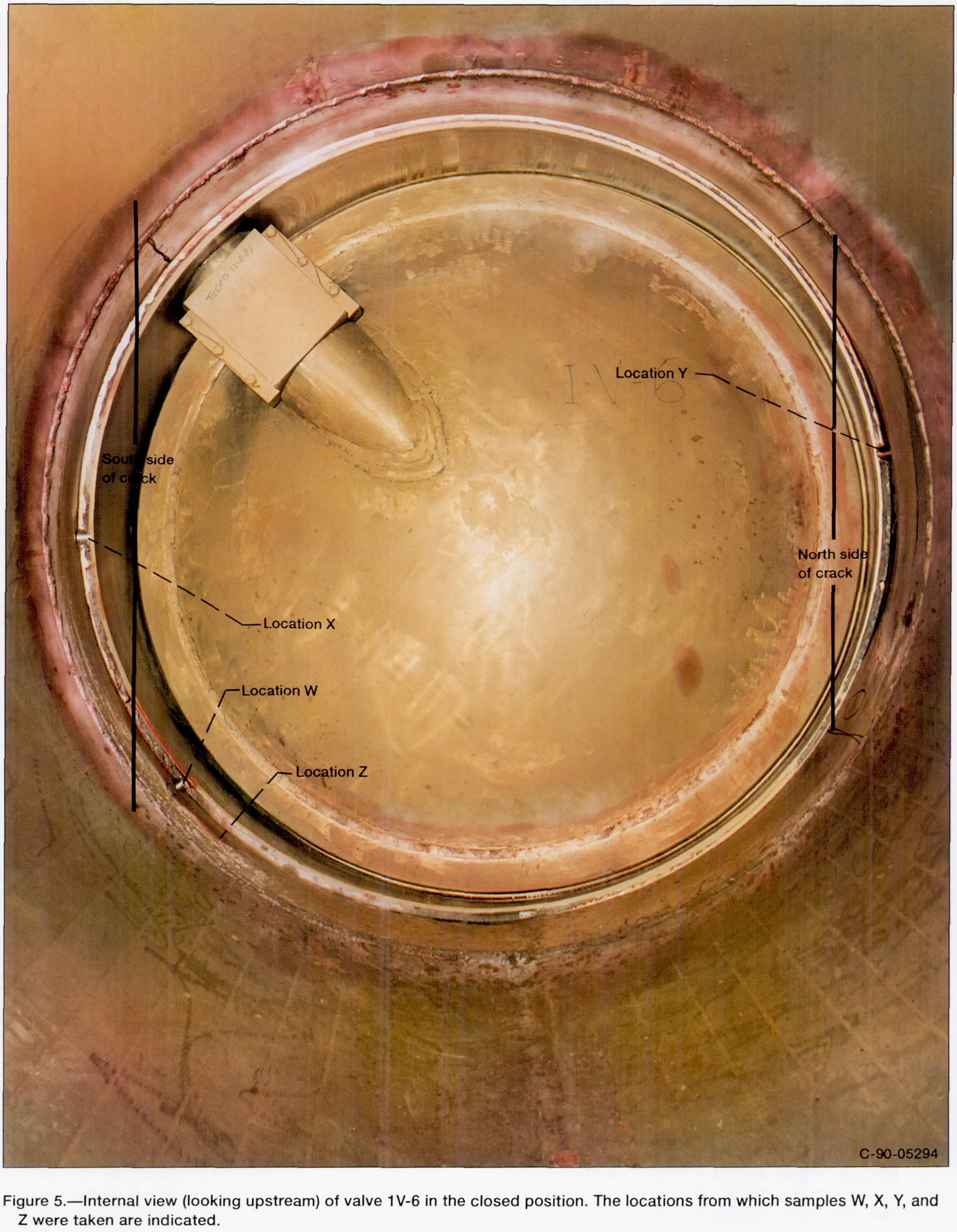


Figure 5.—Internal view (looking upstream) of valve 1V-6 in the closed position. The locations from which samples W, X, Y, and Z were taken are indicated.

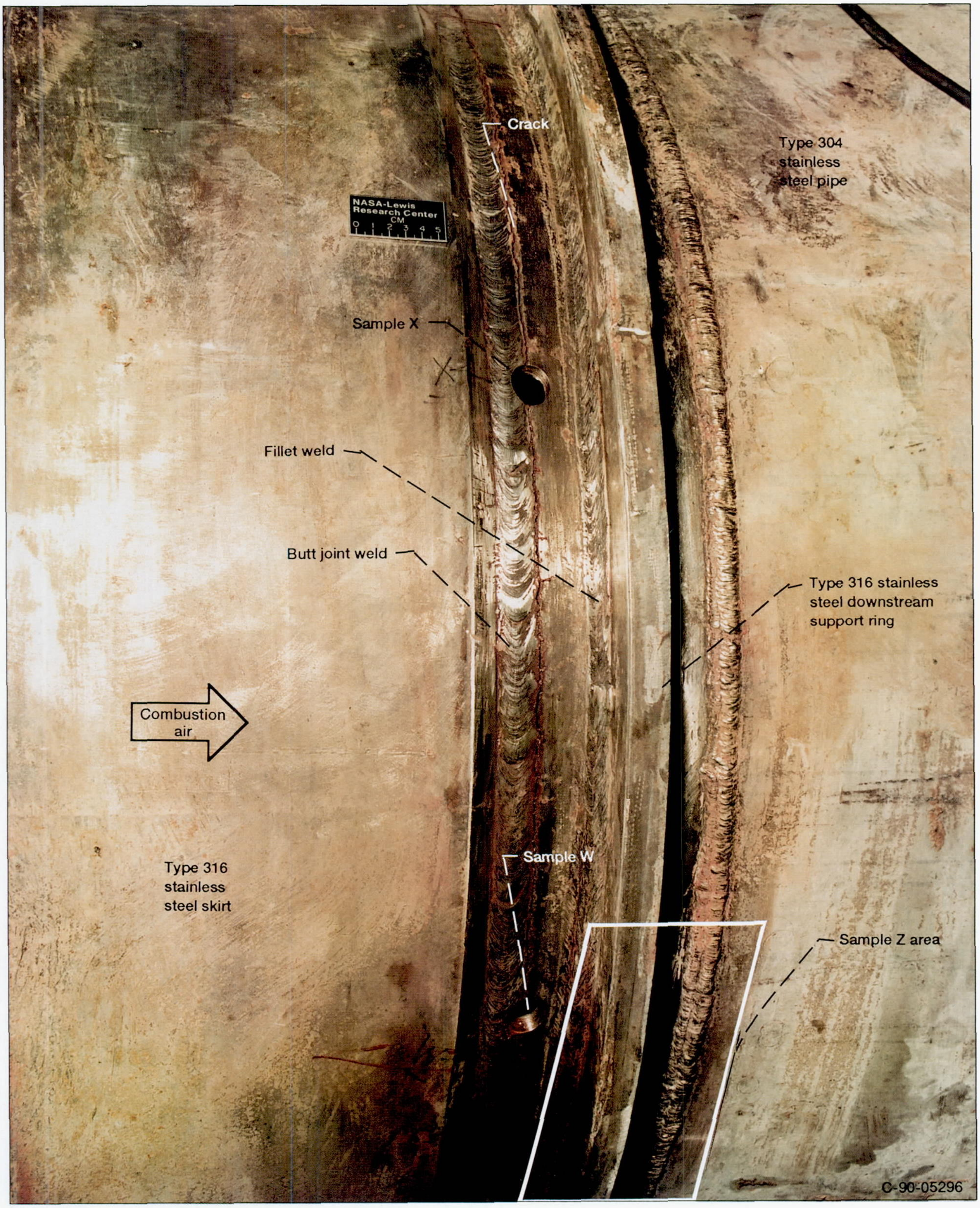


Figure 6.—External view from the south at the downstream side of valve 1V-6 showing plug holes for samples W and X and the area from which sample Z was taken.

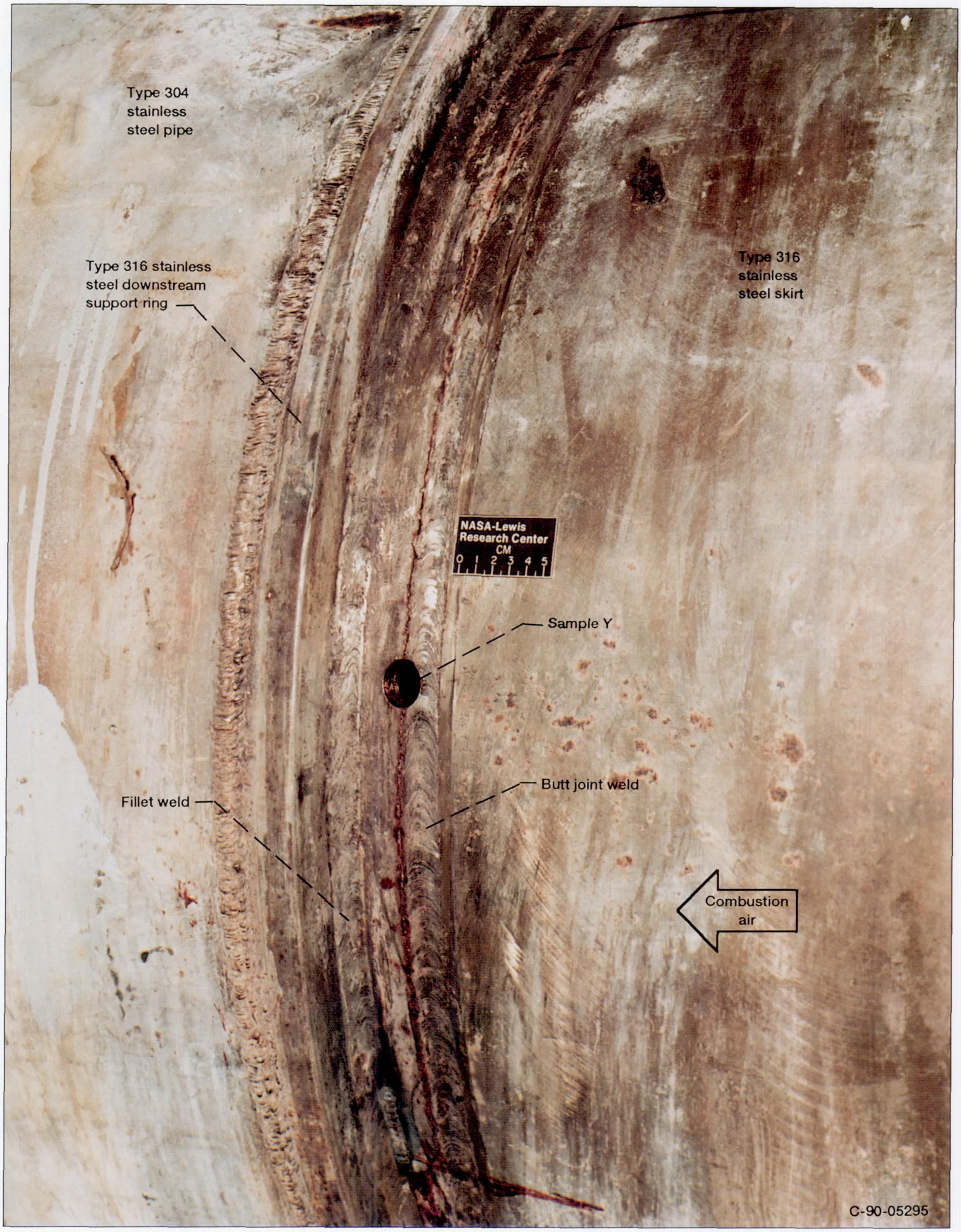
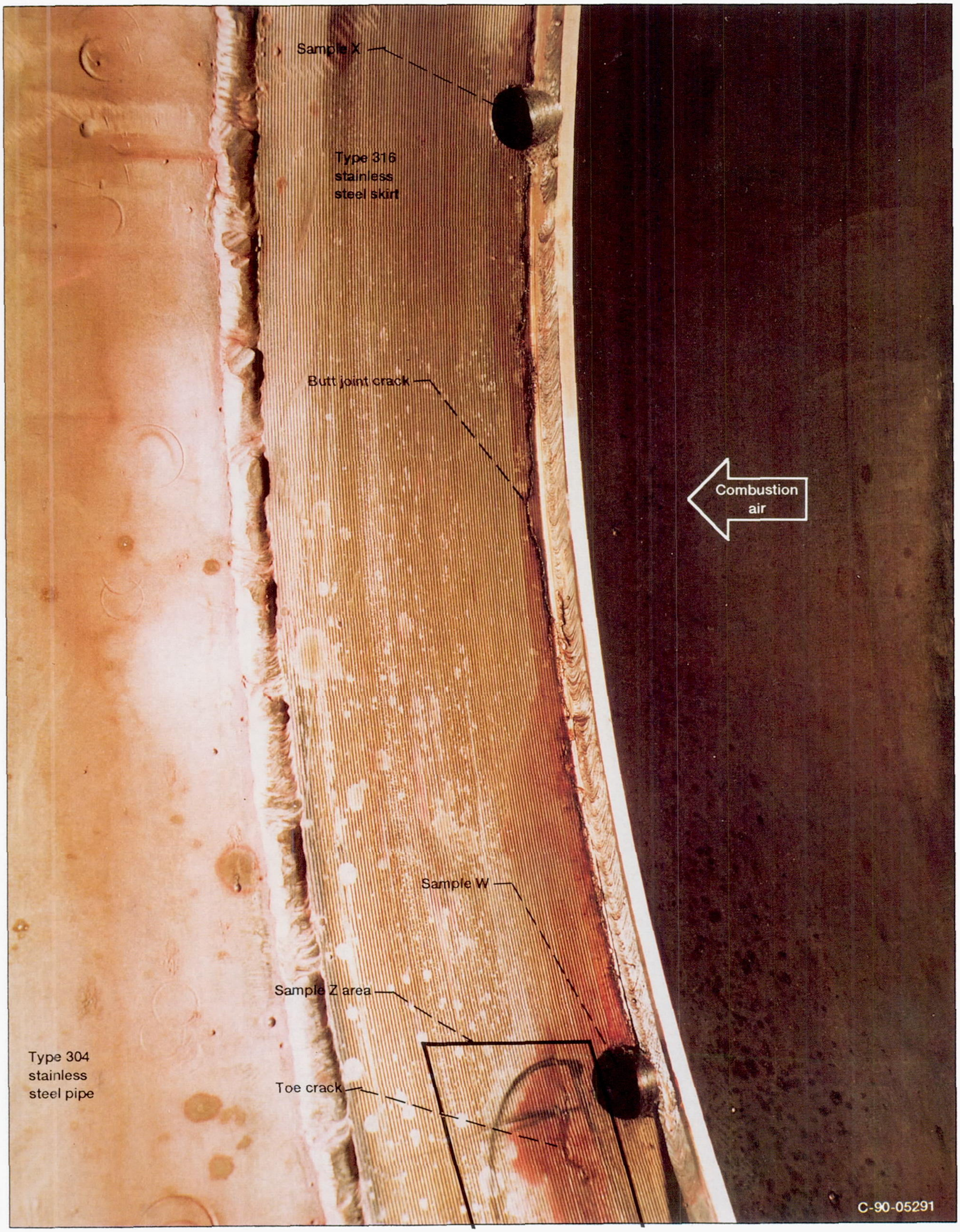
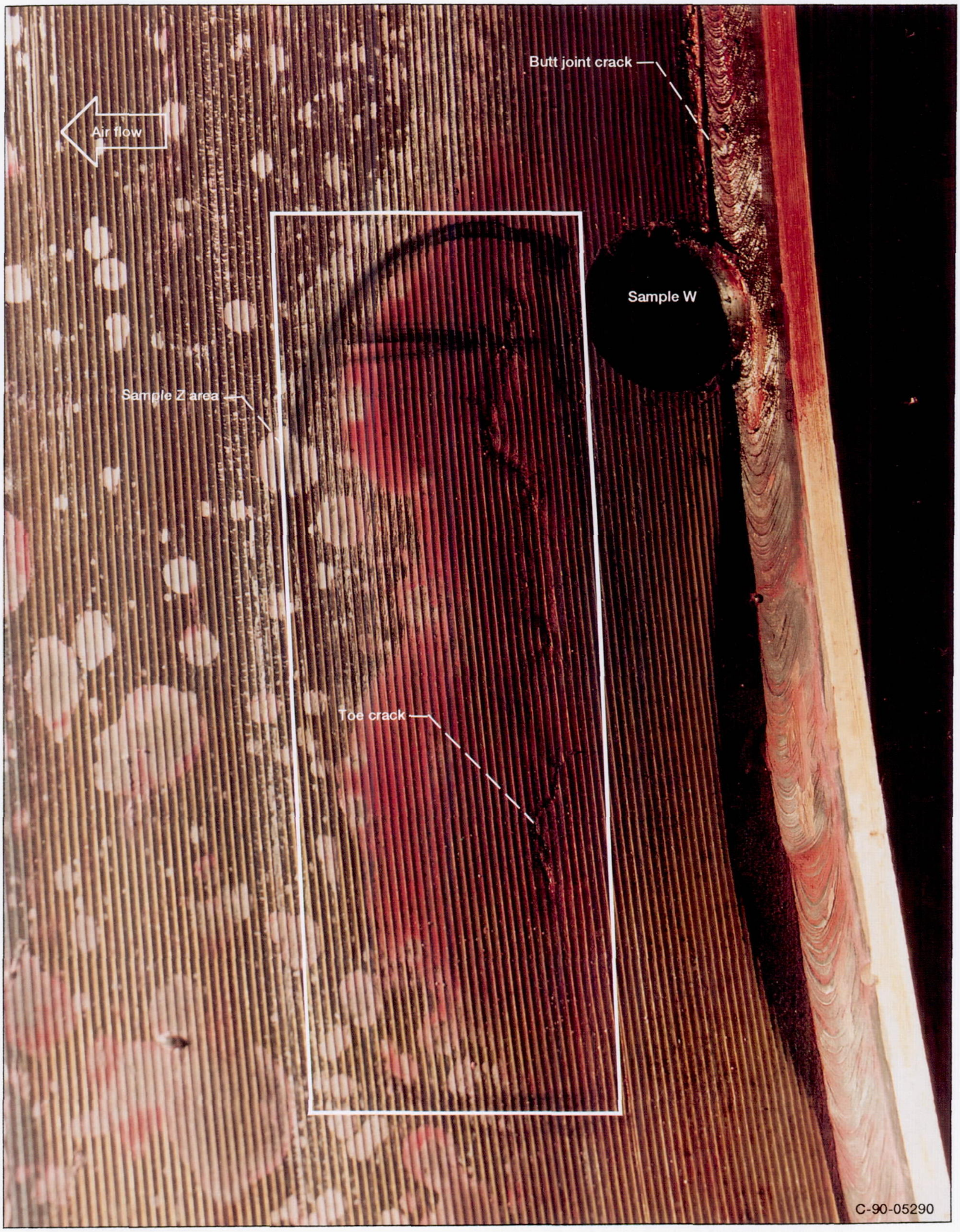


Figure 7.—External view from the north of valve 1V-6 at the downstream side showing plug hole for sample Y.



(a) View of the plug holes of samples W and X and a portion of the area from which sample Z was taken.

Figure 8.—Internal view at the downstream side of valve 1V-6.



(b) Sample W plug hole and region from which sample Z was obtained.

Figure 8.—Concluded.

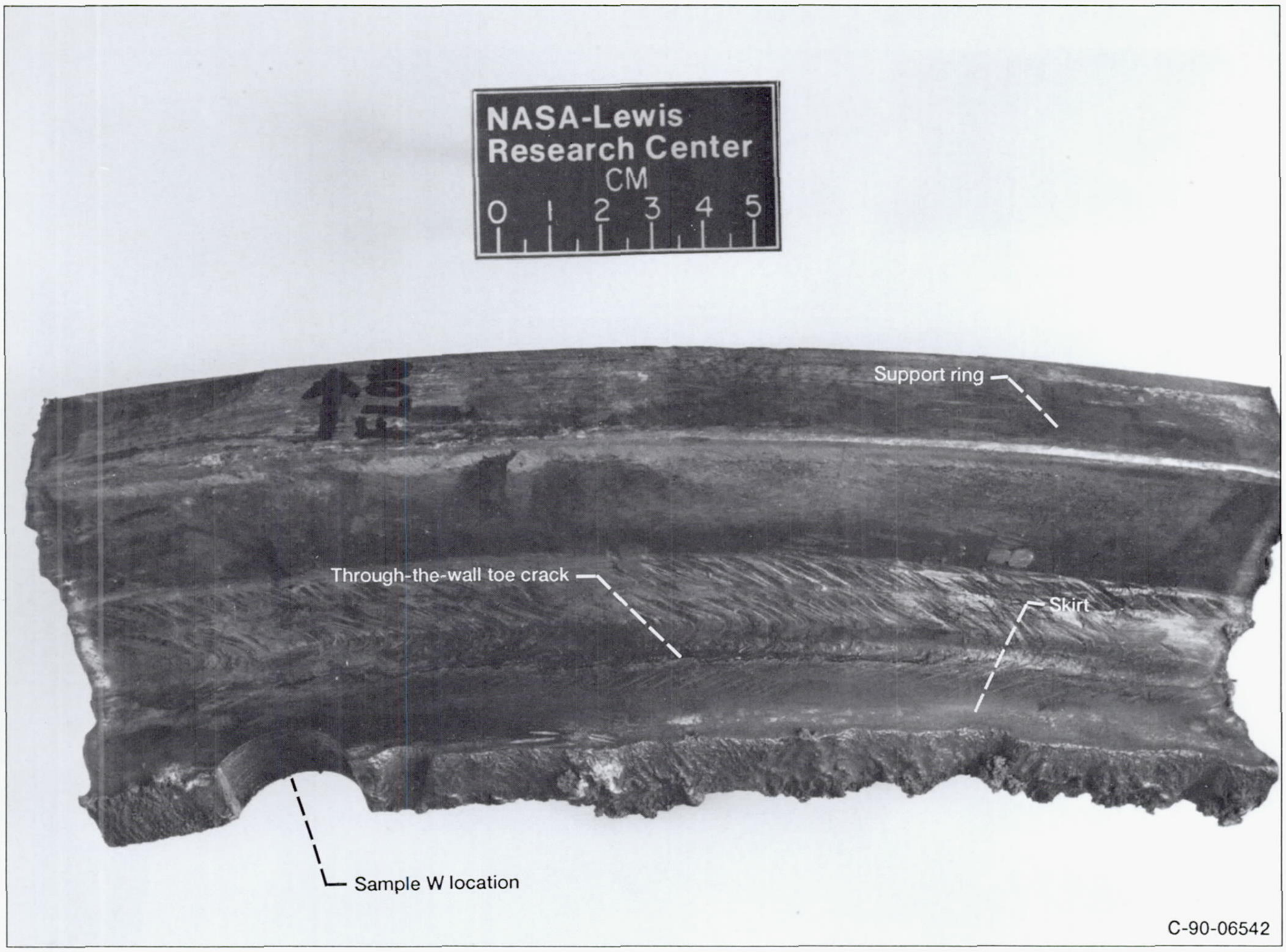


Figure 9.—Sample Z (a 10-cm by 26-cm section of the skirt), including a portion of the downstream support ring T-joint.

Material for chemical analysis was obtained from the valve skirt, the downstream support ring, and the fillet weld metal on both sides of the T-joint. Conventional wet chemistry procedures and emission spectroscopy analysis were used to determine the composition of these materials. A standardless x-ray energy dispersive spectra (XEDS) analysis in a scanning electron microscope (SEM) was made to determine the composition of the weld metal in the butt joint because sufficient material for conventional analysis was not available.

Light microscopy and the SEM were utilized to characterize the microstructure of the cracked regions. In addition, XEDS was used to determine whether foreign elements were present in the vicinity of a crack. Because the specimen examined was mounted in a thermosetting plastic material, XEDS analysis was conducted on this material to determine if infiltration of the plastic material might influence the results.

Water from the cooling towers was analyzed for chlorides. In addition, the insulating materials were analyzed for sodium (Na), potassium (K), and chlorides following the ASTM procedures described in reference 1. The fiberglass samples were taken from the location of the failed valve. It was necessary to prepare a new batch of the asbestos mud for analysis since a sample of this material was not available.

Results

Chemical Analysis of Base Metals and Weld Metals

Conventional chemical analysis determinations at the downstream region of the valve are shown in table I. These data confirm that the valve skirt, support ring, and the weld metal in the T-joint are Type 316 stainless steel. The XEDS analysis shown in table I qualitatively confirms that the weld metal in the butt joint is also Type 316 stainless steel.

Crack at Butt Joint

Plug specimens X and Y both separated into two pieces because at these locations the butt joint crack extended through the full thickness of the skirt. For specimen W, the crack did not penetrate completely through the skirt wall. It is

TABLE I. – CHEMICAL ANALYSIS[a]

Material	Element, wt%											
	C	Mn	Si	Cr	Ni	Mo	S	P	Cl	K	Ca	Fe
(a) Conventional analysis												
Type 316 stainless steel[a]	0.08[b]	2.0[b]	1.0[b]	16.0–18.0	10.0–14.0	2.0–3.0	0.03[b]	0.045[b]	--	--	--	---
Valve skirt	.084	1.8	.6	17.4	13.6	2.2	0.008	0.043	--	--	--	---
Support ring	.052	1.7	.6	17.2	12.3	2.3	.011	.040	--	--	--	---
T-joint weld metal	.049	1.6	.6	18.2	14.2	2.4	---	---	--	--	--	---
(b) X-ray energy dispersive spectra analysis												
Butt joint weld metal	---	1.3	1.2	19.2	13.3	1.7	---	--	--	--	--	63.3
Support ring	---	0.9	1.9	18.5	12.0	0.9	---	0.4	0.1	0	0	64.2
Outer layer	---	1.2	9.9	2.3	5.2	1.5	---	6.0	5.9	0.4	3.8	62.6
Inner layer	---	1.0	1.5	17.5	15.7	0.7	---	0.4	0.5	0.5	0.3	61.4
Intergranular layer	---	1.2	4.7	31.1	12.6	2.3	---	1.3	7.9	0.5	1.6	34.5

[a]Specified analysis.
[b]Maximum.

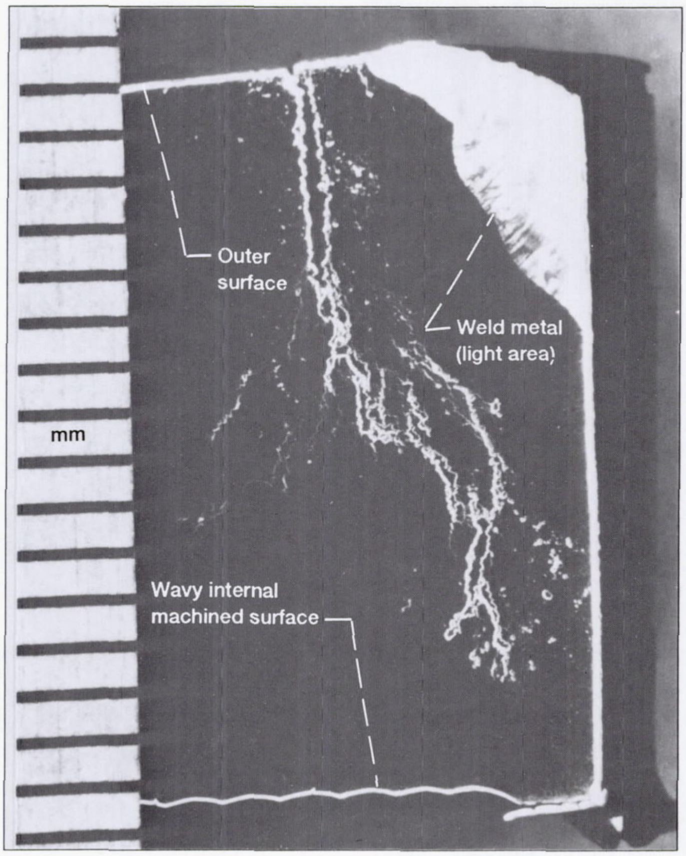
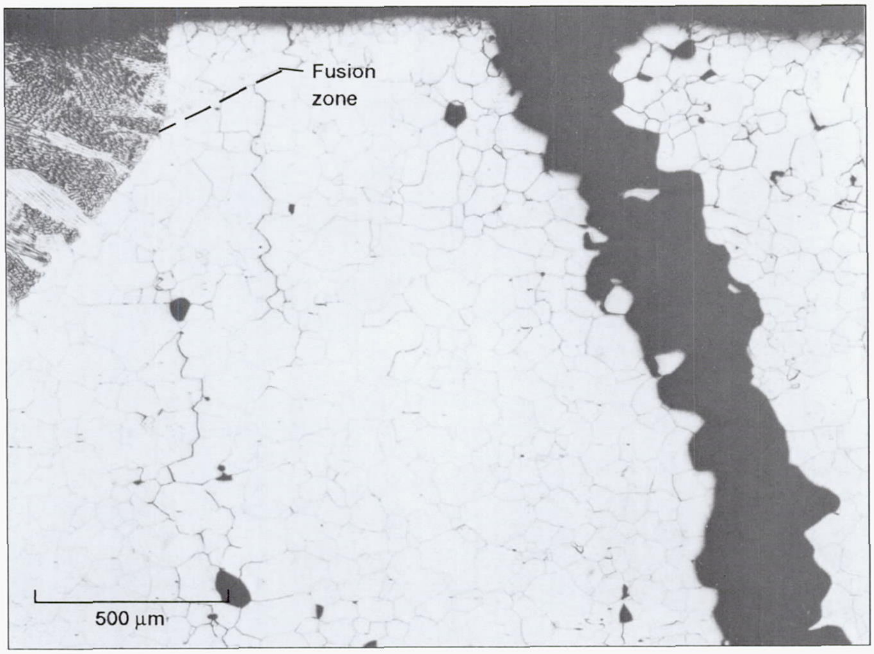
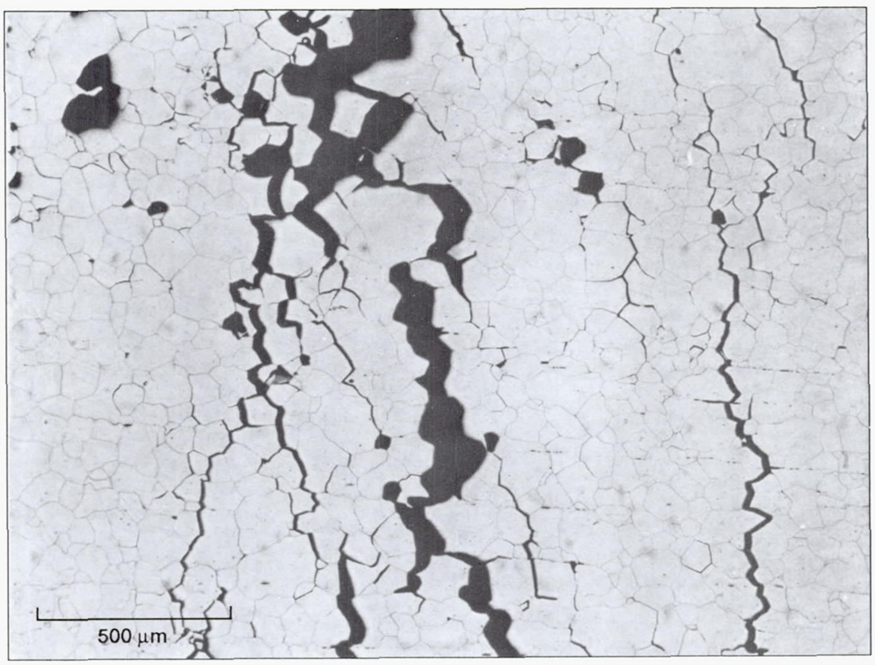


Figure 10.—Macrograph of stress-corrosion cracking in the heat-affected zone of a circumferential butt joint in Type 316 stainless steel (specimen W).



(a) Intergranular, heat-affected-zone crack at outside surface.



(b) Intergranular, base metal cracks at midthickness of the skirt. The cracks are oriented roughly parallel to the main fracture path.

Figure 11.—Intergranular nature of the stress-corrosion cracking in the heat-affected-zone of the circumferential butt joint (specimen W).

evident from the cracking pattern shown in figure 10 that the crack started at the outer surface of the skirt. Below the surface, it became branched. Figures 11(a) and (b) illustrate the intergranular nature of the cracking.

T-Joint Cracks

The cross section of sample Z from the valve skirt (fig. 12) shows a toe crack which extended more than halfway through the wall (location 1). Other cross sections of

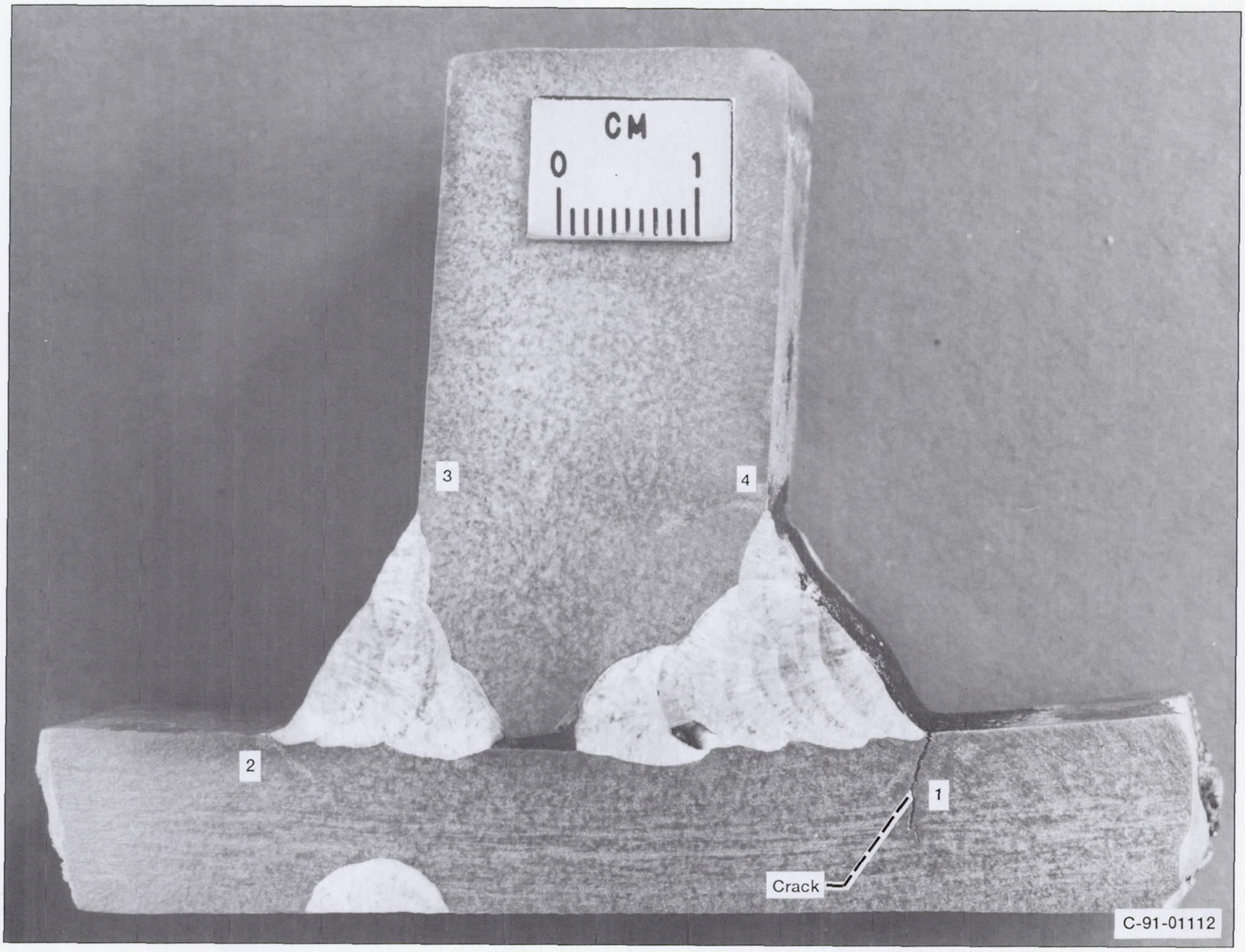


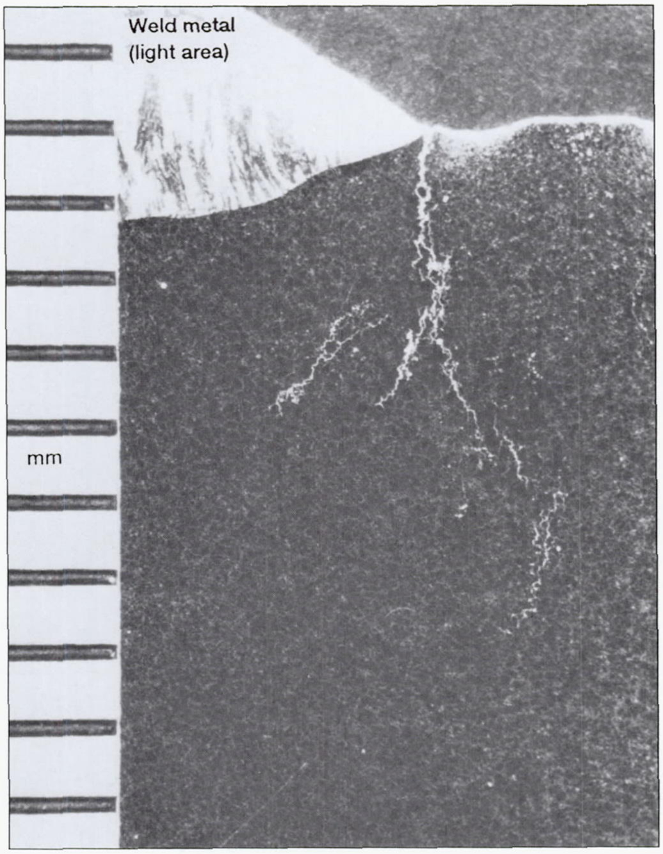
Figure 12.—A cross section of sample Z T-joint showing a stress-corrosion toe crack in the Type 316 stainless steel valve skirt. Intergranular toe cracks (not evident in this photograph) are also present at locations 2, 3, and 4.

sample Z revealed that this crack had penetrated completely through the skirt for a distance of 18 cm along the circumference. Like the butt joint crack, it was narrow at the outer surface and branched as it proceeded towards the interior. The failure was intergranular, similar to that shown in figure 11. Tight, intergranular toe cracks not evident in figure 12 were present at locations 2, 3, and 4. These cracks were found only after sectioning and polishing. The cracking in the skirt at location 2 in figure 12 (shown in fig. 13(a)), extends to a depth of about 7 mm. At location 4 in figure 12, the cracking has progressed into the support ring to a depth of about 8 mm (see fig. 13(b)). At location 3 in figure 12, the cracking was only about 2 mm deep (not shown). The purpose of the autogenous gas tungsten arc weld pass at location 2 in figure 12, on the inner surface of the skirt, is not known.

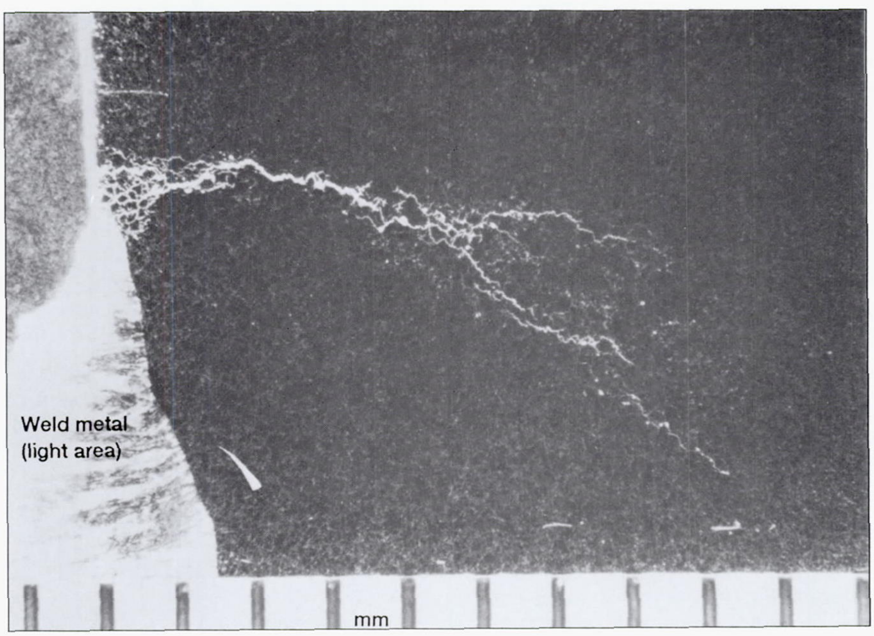
XEDS Analysis at a Crack

The support ring base metal toe crack at location 4 (fig. 13(b)) was the area examined. As shown in figure 14, two oxidelike layers were present at the outside surface, and a number of intergranular cracks extended from this surface into the support ring. The XEDS analysis was performed in three regions designated the outer layer, the inner layer, and the intergranular layer, respectively (fig. 14). XEDS analysis of the support ring was also conducted in a noncorroded area away from the crack.

The XEDS analysis of the mounting material did not give the precise composition of the plastic mounting material because XEDS was unable to measure carbon peaks. This material did show a prominent calcium (Ca) peak and a much



(a) Cracking in the valve skirt at location 2 in figure 12.



(b) Cracking in the support ring at location 4 in figure 12.

Figure 13.—Intergranular, stress-corrosion cracking at a T-joint in the Type 316 stainless steel valve.

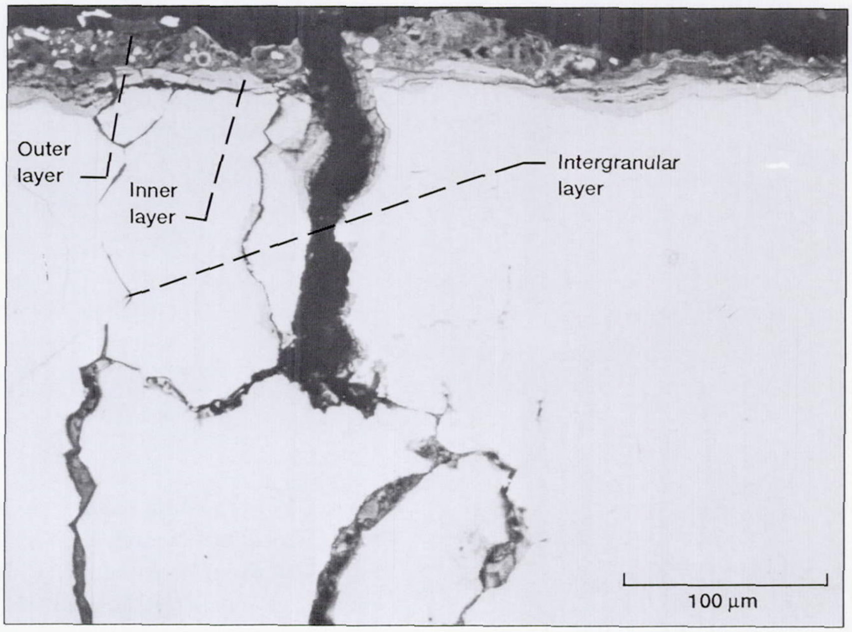


Figure 14.—Backscatter scanning electron microscope image showing intergranular, stress-corrosion cracking and the locations that were analyzed.

smaller but significant silicon (Si) peak. Another factor considered in the discussion to follow is that the XEDS standardless analysis has questionable accuracy when less than 1 wt % of a specific element is present.

The base metal support ring spectra are shown in figure 15. A comparison of the support ring analysis as determined by XEDS and conventional methods can be made using the data in table I. This comparison shows general agreement except for the lower molybdenum (Mo) content in the XEDS analysis.

A major difference in composition between the outer layer (fig. 14) and the support ring can be noted in the XEDS analysis in table I. First, the relative levels of chromium (Cr) and nickel (Ni) in the outer layer are significantly lower. Second, the outer layer appears to contain substantial quantities of chlorine (Cl), Ca, Si, and phosphorus (P). The Ca and Si indications are probably a result of plastic mounting material infiltration. But the presence of Cl, P, and possibly K are believed to result from the environment in which the valve operated. Analysis of the inner layer (shown in table I) indicates that this material is essentially Type 316 stainless steel.

Perhaps the most important information was obtained from the analysis of the intergranular layer, 150 μm below the surface of the cracked ring (fig. 14). The profile for this spectra is shown in figure 16. These data are given in table I. A comparative XEDS analysis of the base metal and the intergranular layer showed increased quantities of Cr (18.5 to 31.1 percent), Cl (0.1 to 7.9 percent), and P (0.4 to 1.3 percent). The high Cr indicates the presence of chromium carbides at the grain boundaries (i.e., a sensitized condition). In this condition, the grain boundary regions adjacent to the carbide particles are low in Cr and are thus susceptible to corrosive attack. The presence of a relatively large quantity of Cl is significant because of the key role this element plays in stress-corrosion cracking (SCC). The indicated increases in P and K may have resulted from the operational environment. Indications of higher Ca and Si are believed to be spurious, probably resulting from the plastic mounting material.

Analyses of Water and Insulation Materials

The results of the analyses of the cooling tower water are presented as a range; the results of the analyses of the insulating materials are reported as individual values in table II. These analyses show that chlorides were present in the leachate from the fiberglass at the time the failure was discovered. However, it is not known what proportion of the chlorides came from the cooling tower water and what proportion came from the as-manufactured fiberglass. A very low level of chlorides was present in the asbestos mud. The higher concentration of chlorides in the tower 2 water (in comparison to the other tower systems) is due to the fact that tower 2 is a smaller system with a lower volume of water.

Discussion

The progressive failure of a Type 316 stainless steel valve skirt took 18 years. Although the failure occurred near welded joints, no defects were discovered in the joints as the welding workmanship was excellent. With the exception of the narrow regions of cracking, this intergranular, base metal cracking failure was a noncatastrophic event because the

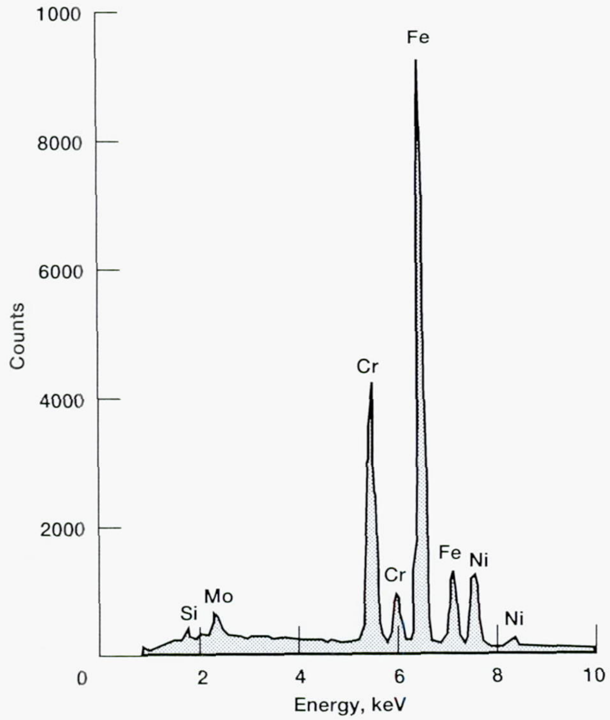


Figure 15.—Type 316 stainless steel matrix spectra.

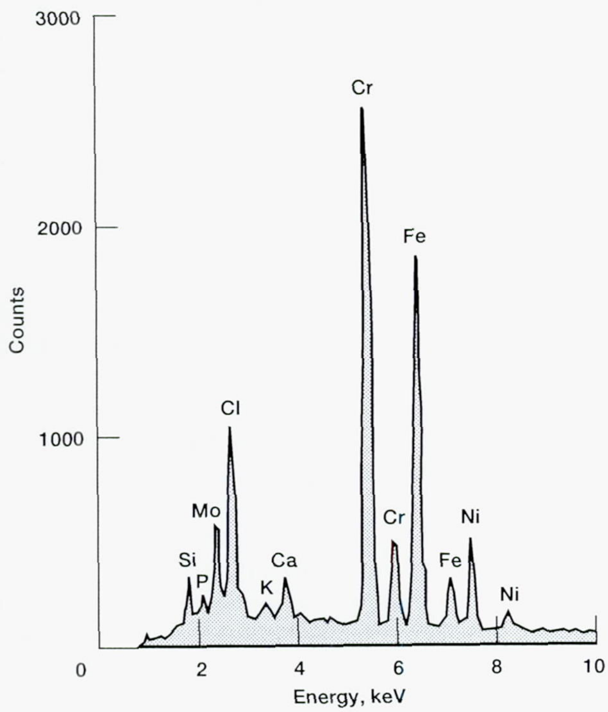


Figure 16.—Intergranular, stress-corrosion crack spectra.

properties of high ductility and strength are not believed to have been affected. Also, the initiation points for both the major and minor cracks were located at the outer surface of the valve.

Since the massive 1V–6 valve weldment was used in the as-welded condition, residual tensile stresses on the order of

TABLE II.—ANALYSIS OF COOLING TOWER WATER AND INSULATING MATERIALS

[Cooling tower water results are in ppm per weight of water; insulating material results are in ppm per weight of insulation]

Material	Element, ppm		
	Chlorides	Potassium	Sodium
Asbestos mud	2.8, 5.4	180, 110	1700, 620
Fiberglass	70, 140, 180	620, 230, 410	1990, 900, 1490
Towers			
3 and 6	40 to 60	------	-------
2	100 to 200	------	-------
1 and 4	40 to 60	------	-------

200 to 275 MPa could have been present at the weld joints (ref. 2). Local postheating at 650 °C might have reduced the stresses by about 35 percent (ref. 3), but this heat treatment would have sensitized the Type 316 material to some extent (i.e., the sensitized material being that portion of the HAZ that was exposed to temperatures of 550 to 850 °C for a sufficient time during welding to precipitate chromium carbides). The corrosive medium was aqueous chloride at the outer surface of the valve. The XEDS analysis of material in the cracked grain boundaries revealed a significant quantity of chlorine.

On the basis of the failure analysis, all the conditions required for intergranular stress-corrosion cracking (SCC) were met: SCC occurs when a sustained tensile stress and a chemical attack combine to initiate and propagate failure (ref. 2). SCC is insidious because fine cracks that are very difficult to detect at the outer surface may penetrate deep into the part. Takemoto (ref. 4) reported that external SCC can occur when the chloride concentration at the surface is 100 ppm. However, SCC can occur at a chloride concentration of 10 ppm or less, as reported in reference 5. Therefore, because SCC cracking is initially extremely tight, ultrasonic shear wave and acoustic emission procedures were sometimes used to supplement liquid penetrant inspection techniques (ref. 6).

Takemoto (ref. 4) showed that, at a stress of 245 MPa in sensitized stainless steel, SCC occurs in about 80 hr at 90 °C. The critical temperature range for SCC was between 35 and 110 °C. Ashbaugh (ref. 6) gave an approximate SCC temperature range of −18 to 177 °C. The failure of valve 1V–6 was first discovered at the downstream, hotter side that was sometimes exposed to air temperatures ranging from 340 to 370 °C. During a detailed inspection, additional external SCC was discovered at the upstream side of the valve that operated at ambient temperature. Thus, when the broad temperature ranges are considered, it is probable that the SCC progressed in the HAZ of the Type 316 stainless steel weld joints from the outer surface both during and between runs.

Stress-corrosion cracking in austenitic stainless steel can be intergranular or transgranular. The nearly exclusive intergranular path of the cracks in this case is typical of sensitized austenitic stainless steel in which chromium-depleted zones along grain boundaries are anodic to the main body of the grains (refs. 2 and 7). Substitution of Type 316L for Type 316 stainless steel would alleviate sensitization in the weld HAZ because of the lower carbon content. This change would probably delay the cracking and change the mode from intergranular to transgranular. Type 316NG stainless steel (0.02 percent carbon and 0.06 to 0.1 percent nitrogen) would be an even more desirable substitute material because it has significantly greater resistance to intergranular SCC (ref. 8). Local postheating could be applied to the low-carbon grades for the reduction of residual tensile stresses without producing a sensitized microstructure.

If a Ni-base alloy such as Incoloy 800 were used, SCC would not be a problem (ref. 2). However, using this alloy would be impractical because of cost and other factors. A more practical approach would be to utilize the high SCC resistance of mild steel (ref. 5). In this approach, the valve would be fabricated from stainless-clad mild steel, with the mild steel at the outer surface; the interior of the skirt and the butterfly valve would be stainless steel; and the support rings would be mild steel.

Even in the presence of residual tensile stresses, SCC would not be a problem if aqueous chlorides were not present at the outer surfaces. This condition would exist if no leachable chlorides were present in the insulation and if the cooling tower water mist were prevented from contacting valve 1V–6, which might be accomplished by covering the drain basin. With an uncovered drain basin, an absence of chlorides would be possible only if chlorides were not present in the city water coming in to the cooling towers and if no chemicals containing chlorides or chlorine were added to the water. In this latter regard, an alternative to using biocides to treat cooling tower water would be to use ozone (refs. 9 to 11). In Europe in potable water supplies, ozone is used for sterilization and bacteria control because of its strong oxidizing capability. However attractive, ozone does not eliminate chlorides from the city water. Thus, complete demineralization or deionization would be required for 2.3 million gallons of water.

If the complete elimination of chlorides cannot be assured, the application of an adherent, greasy substance at the weld joints could isolate these critical surface regions from the corrosive media. A basic requirement is that the grease cover the metallic surface and not deteriorate with time and temperature. In industrial applications, thermosetting tape coatings have been an effective countermeasure to external SCC under thermal insulation on Type 304 stainless steel (ref. 4). The service temperature range for this kind of tape is from −60 to 540 °C (ref. 12). Other surface treatments that show promise include thermally sprayed coatings of aluminum, aluminum foil wrapping, and painted coatings (refs. 4 and 12).

Countermeasures designed to introduce compressive stress at the exterior surfaces of welded joints are highly effective means of eliminating the SCC problem. Shot-peening is one method that has been used (refs. 4,13, and 14). Another approach is to use special welding procedures and heat treatment. References 5 and 15 describe work in which compressive stress was produced at the inside surface of pipe joints because that was where SCC originated. The failed valve 1V–6 differs in both the size of the weldment and the location of SCC initiation. Thus, an effective countermeasure for valve 1V–6 would be to use welding procedures that would produce compressive stresses at the outer surfaces of the circumferential butt joint and T-joints. A third method designed to produce compressive surface stresses utilizes shock waves produced by explosives. In the former Soviet Union, this approach was effectively used for large welded structures. It has been used only experimentally in the United States (refs. 16 and 17).

Welding processes in which fluorides are present in the arc atmosphere (such as shielded metal arc welding) should be avoided (ref. 4). Fortunately, SCC problems due to the presence of fluorides were not encountered in this investigation because only gas tungsten arc and gas metal arc processes were used

Conclusions

1. The skirt of a 1.22-m-diameter by 15-mm-wall Type 316 stainless steel combustion air supply valve failed as a result of external stress-corrosion cracking.

2. The failure was caused by a combination of residual tensile stresses from welding and the presence of aqueous chlorides at the outer surface of the valve.

Recommendations

Countermeasures designed to prevent stress-corrosion cracking in the present Type 316 stainless steel valve should include one or more of the following:

1. A cover for the drain basin to prevent the major source of cooling tower water mist from contacting the outer surfaces of the valve
2. A reduction in chemical additions that contribute chlorides to the cooling tower water
3. A study of ozone additions as a means of treating the cooling tower water
4. Water-tight coatings at all welded joints
5. Substitution of a chloride-free, nonwicking insulating material for the fiberglass
6. Local postheating at 650 °C for 1 hr to reduce the residual tensile stresses in repair welds in valve 1V–6
7. Shot-peening, where accessible, the exterior surfaces of all welded joints

In the design and fabrication of a new 1V–6 valve, the following should be considered:

1. The use of stainless-clad mild steel material for the skirt and mild steel for the support rings

2. Type 316NG material for the skirt and rings if austenitic stainless steel is chosens

For long-range studies, the development of additional countermeasures to combat stress-corrosion cracking in large structural weldments is recommended. Especially attractive is applied research designed to eliminate residual tensile stresses at outer surfaces that may be exposed to corrosive media. Two of these study areas worthy of support are (1) the development of special welding and heat treating procedures and (2) the utilization of shock waves from explosives.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, May 22, 1992

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An investigation was conducted to determine the cause of the failure of a massive AISI Type 316 stainless steel valve which controlled combustion air to a jet engine test facility. Several through-the-wall cracks were present near welded joints in the valve skirt. The valve had been in outdoor service for 18 years. Samples were taken in the cracked regions for metallographic and chemical analyses. Insulating material and sources of water mist in the vicinity of the failed valve were analyzed for chlorides. A scanning electron microscope was used to determine whether foreign elements were present in a crack. On the basis of the information generated, the failure was characterized as external stress-corrosion cracking. The cracking resulted from a combination of residual tensile stress from welding and the presence of aqueous chlorides. Recommended countermeasures are included.

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