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**Analysis of Blind Flange and Thermowell
Assembly from Wilsonville, Alabama,
Solvent Refined Coal Plant
Dissolver Tank**

J. H. DeVan
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METALS AND CERAMICS DIVISION

ANALYSIS OF BLIND FLANGE AND THERMOWELL ASSEMBLY FROM
WILSONVILLE, ALABAMA, SOLVENT REFINED COAL PLANT
DISSOLVER TANK*

J. H. DeVan, B. C. Leslie, and R. T. King

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ABSTRACT

A type 316 stainless steel blind flange and thermowell assembly rated at 17 MPa (2500 psi) was removed from service at the Wilsonville Solvent Refined Coal (SRC) plant when cracks were observed on the flange face. Metallographic examination revealed a system of cracks that penetrated a repair weld and extended into the base metal on the face where it was exposed to the process media. The cracking in the weld metal appeared to follow substructural boundaries. A second crack network initiated in the disturbed base metal beneath a ground surface and extended through a tenth of the flange thickness. Cracking in the base metal was transgranular. Neither the corroding species nor the local stress level responsible for the cracking can be specified.

SOURCE OF PART

The Southern Company System and the Edison Electric Institute (EEI) jointly began the pilot plant study of key steps in the solvent refining process for making low-sulfur and low-ash solid fuel from coal in March 1972. Southern Company Services, Inc. (SCS) represents the Southern Company System and provides management for the project. In April 1973, the Electric Power Research Institute (EPRI) assumed the functions of utility industry project supervision, which were formerly carried out by EEI.

The United States Energy Research and Development Administration (ERDA) joined in the sponsorship of this project for the calendar years 1976 and 1977.

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The six-ton-per-day solvent refined coal (SRC) pilot plant was designed, and constructed and is being operated by Catalytic, Inc., at Wilsonville, Alabama. Operation with coal began January 1974.

DESCRIPTION OF PART

The blind flange and thermowell assembly is shown in Fig. 1 as it was received at ORNL for examination. Stamp marks identify the blind flange as 2500 psi-rated, A182, F316 material. It is about 235 mm in diameter and 51 mm thick at the bolt holes. The center is thicker, having a raised face about 100 mm in diameter. A thermowell made of two sections of schedule 40 standard pipe (approximately 20.6 mm OD by 4 mm wall thickness) is welded into the center of the blind flange. A gas sampling line is welded into the flange with its center line approximately 25 mm from the center of the flange.

DESCRIPTION OF SERVICE CONDITIONS AND LIFE

The Wilsonville solvent-refined coal plant and its operating history are described in a series of progress reports.¹

The blind flange and thermowell assembly covered a nozzle penetrating the dissolver tank about halfway up the tank. The assembly was part of the original plant installation, having been used since the plant start-up in late 1973 for a total of 3 1/2 years of service before removal in June 1977. As part of the pressure boundary, the inner face of the assembly was exposed to variations in nominal pressure from 9.6 to 17.2 MPa (1400–2500 psi) at temperatures in the 415 to 524°C (900–975°F) operating range. In June 1977, the plant staff attempted

¹H. E. Lewis, *Quart. Tech. Prog. Rep. January–March 1976, Solvent-Refined Coal Pilot Plant at Wilsonville, Ala.*, FE-2270-1; *Ibid.*, April–June 1976, ... , FE-2270-3; H. E. Lewis et al., *Solvent Refined Coal (SRC) Process Operation of Solvent Refined Coal Pilot Plant at Wilsonville, Ala. Quart. Tech. Prog. Rep. July–September, 1976*, FE-2270-10; *Ibid. Annu. Tech. Prog. Rep. January–December, 1976*, FE-15; *Ibid. Quart. Tech. Prog. Rep. January–March 1977*, FE-2270-19; *Ibid. April–June 1977*, FE-2270-24; *Ibid. July–September 1977*, FE-2270-27.

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Fig. 1. The Blind Flange and Thermowell Assembly as Received from the Wilsonville Solvent Refined Coal Plant. (a) The side of the blind flange exposed to the process media. The small hole at about two o'clock is the gas sampling port. Note the cracking near the weld joining the thermowell to the blind flange. (b) The outside surface of the blind flange.

to remove the assembly for inspection, but the thermowell was coked in place and could not be removed manually. A 4-kN (1000-lb-force) "come-along" was used to free the assembly. Cracking of the flange adjacent to the weld joining it to the thermowell was obvious when the assembly was cleaned at the plant (see Fig. 2). Consequently the assembly was replaced.

ANALYSIS

The cracking network visible in the blind flange extended as far as about 15 or 20 mm from the root of the weld joining the thermowell to the flange (see Fig. 2). A pattern of heavy grinding or scratch marks was observed on the flange face in the area of cracking.

Two pie-shaped wedges were sawed from the assembly for detailed metallographic analysis (see Fig. 3). One was rough-polished and macro etched to reveal the locations of cracks, so that a smaller section suitable for mounting could be cut from it. The extent of the cracking in the macroetched pie-shaped section is shown in Fig. 4; the deepest cracks observed extended 6 to 7 mm into the blind flange. The structure of the fused material suggests that a weld repair had been made on the surface near the thermowell and ground flat, and then a separate fillet weld was made to join the thermowell to the flange. Cracks penetrated the ground repair weld and the base metal under it. Other cracks that are probably not connected with those in the repair weld exist in the base metal under the ground surface. The large crack closest to the thermowell was probably enlarged by handling while the specimen was being removed. The second pie-section was polished and etched with $\text{H}_2\text{O}-\text{HNO}_3$. The cracking in the base metal was again branched and transgranular (see Fig. 5).

The smaller mounted sample from the first wedge was polished and etched in $\text{H}_2\text{O}-\text{HNO}_3$. The tip of the longest crack is shown in Fig. 6 in both the etched and unetched conditions. The multiply branched crack is transgranular, with no intergranular separations visible. A duplex grain structure was observed in both sections, with cracking prominent in both the coarse-grained and fine-grained regions. Cracking

Fig. 2. Cracks in the Inner Surface of the Blind Flange and Thermowell Assembly. Note grinding marks on the as-received surface. The port for gas sampling is a small hole visible in the upper right corner of (a).

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Fig. 3. The Fabrication of the Assembly Involved Two Pipes Welded to the Flange, as Seen After Removing One Wedge of Material. Also note the surface-ground region about the thermowell insert.

Fig. 4. Cracks in Rough-Polished and Etched Section of Weld Joining Thermowell to the Inside of the Blind Flange Extended Through Both Weld Metal and Base Metal. 4 $\times$.

through the repair weld region (see Fig. 7) tends to follow substructural boundaries and extends into the base metal in the same transgranular fashion that was observed in regions not under the repair weld.

The sample shown in Fig. 4 was analyzed at the ORNL spectrochemical laboratory. The forged blind flange, the fillet weld, and the pipe were examined separately by semiquantitative methods to verify their approximate compositions. Results listed in Table 1 are consistent with identification of all parts and welds as type 316 stainless steel.

The polished and etched microstructure of the blind flange revealed regions with extensive slip bands and twinning. Heavily deformed regions were observed just beneath the surface (Fig. 8). While some of this deformation pattern may be residual work from the forging operation, the most heavily deformed regions appear to be associated with grinding marks on the surface of the weld repair region

Fig. 5. Cracking at the Surface of the Type 316 Stainless Steel Blind Flange Occurs in Both Coarse-Grained and Fine-Grained Material. (a) 100× (b) 500×.

Fig. 6. Tip of Longest Crack Shown in Fig. 4, 50 $\times$. (a) Unetched. (b) Etched, showing transgranular nature of cracking.

Fig. 7. Cracking Extending Through Repair Weld Region Into Base Metal. 50 $\times$.

Table 1. Chemical Contents of Blind Flange, Fillet, Weld, and Schedule 40 Pipe Obtained by Spectrochemical Analysis, and ASTM Chemical Specifications

Element	Content, wt %					
	Blind Flange	Fillet Weld	Repair Weld	Pipe	A 213-75, TP316	A 182, F316
Si	0.52	0.5	0.5	0.6	<0.75	<1.0
Mo	2.5	2.6	2.5	2.5	2.0-3.0	2.0-3.0
Cr	17.0	17.0	18.0	17.0	16.0-18.0	16.0-18.0
Ni	14.0	14.0	14.0	14.0	11.0-14.0	10.0-14.0
Mn	1.7	1.7	1.7	1.5	<2.0	<2.0

Fig. 8. Deformation Bands Near the Surface of the Blind Flange.
(a) 200 $\times$. (b) 500 $\times$.

(Figs. 2 and 3). All observed cracking of the base metal surface occurred in the region that had been ground. We were not able to locate the point(s) of origin of the cracks.

From these observations and the history of the blind flange and thermowell assembly that operated at the midpoint of the dissolver tank at the Wilsonville solvent-refined coal plant, the following statements can be made:

1. Both the forged type 316 stainless steel blind flange and the type 316 stainless steel repair weld on it exhibited stress-corrosion cracking after exposure to process conditions for about 3 1/2 years. The observed cracks extended through about 10% of the flange thickness.
2. The cracking tended to follow substructural boundaries in the weld metal and to be transgranular in the base metal.
3. The temperature, local stress, and corroding species leading to attack are not known; cracking could have occurred at the operating temperature (415 to 524°C) or during transients.
4. Cracking occurred in areas that apparently had been ground after a weld repair and in the repair weld, both of which are probably regions of high residual stress.

RECOMMENDATIONS

The following recommendations are offered:

1. Surfaces of accessible portions of the dissolver tanks of the solvent refined coal plants, associated hardware, and other parts of the plant that operate under high pressure should be examined periodically. Ultrasonic examination of critical regions should be considered.
2. Operations that introduce residual cold work into austenitic steels that are exposed to process media should be avoided whenever possible, and particular care should be paid to in-service examination of exposed regions. Weld heat-affected zones should also be given close attention. Postweld heat treatments may be performed to anneal regions of residual cold work.

3. An experimental program to determine which materials of construction and metallurgical conditions are sensitive to cracking under the conditions found in solvent-refined coal plants should be initiated to provide data for construction of large plants. The corro-
dent species, time, temperatures, and stress exposures involved in cracking should be determined.

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