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EXAMINATION OF AN OIL SEPARATOR PRESSURE VESSEL (CASE HISTORY)

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BACKGROUND

A medium pressure oil separator 200 cm O.D, approximately 800 cm long and 1.5 cm wall thickness was removed from service after observing signs of pitting and surface damage. It had been in service for nearly 23 years. The pressure vessel was made of carbon-silicon steel plate, ASTM A515 (Grade 70). The internal pressure was approximately 2.5 bars and the temperature was in the neighbourhood of 50^0C. The pressure vessel was subjected to mechanical and metallurgical testing in order to determine the nature and extent of damage and its influence on the mechanical properties after all those years of service. It was decided to carry out the following tasks:

1. Determination of rolling direction of plates by metallography.
2. Tensile testing to determine UTS, Y.S. and elongation for longitudinal and transverse directions.
3. Charpy "V" notch impact testing at room temperature for both longitudinal and transverse directions.
4. Examination of the nature and extent of damage of the plate.

The ultimate goal was to generate enough information and to relate the results of metallographic examinations to results of non-destructive testing in order to identify a reliable and practical failure criterion for such pressure vessels. This paper will be confined to reporting the results of mechanical and metallurgical testing on one of the pressure vessels.

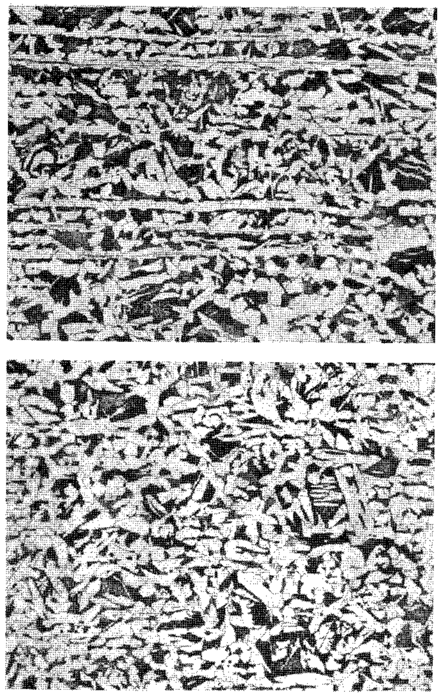
EXPERIMENTAL WORK AND RESULTS

Metallographic Examination

Determination of Rolling Direction

In order to determine the rolling direction of the vessel plates, longitudinal and circumferential sections were taken from the plates, encapsulated in thermosetting plastic and polished to a one micron finish. The polished specimens were etched using Nital (2%) and examined with a microscope.

Typical microstructure of the plate is shown in Figure 1 (a) and (b) for longitudinal and transverse directions, respectively.



(a)

(b)

Fig. 1: Microstructure of the Plate, Etch:Nital (200X)

(a) Circumferential direction — Notice the elongated grains

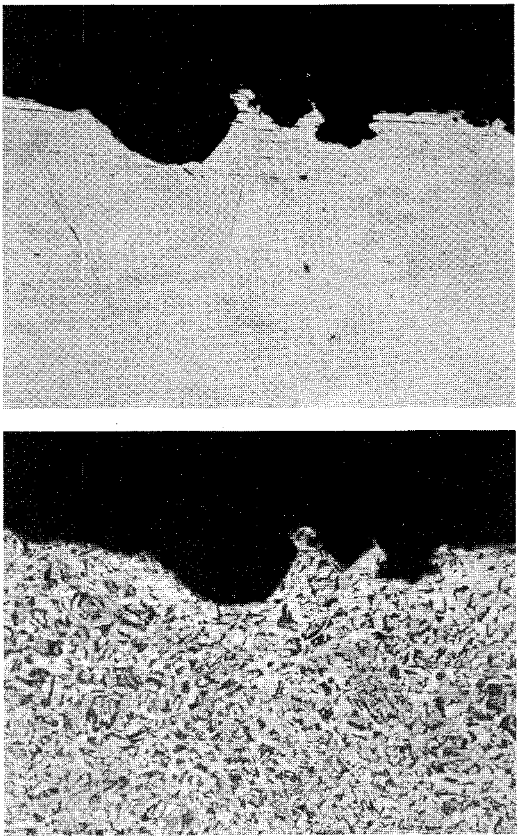
(b) Longitudinal direction

Nature and Extent of Damage

Cracking and peel-off were observed during machining of the test specimens of the plate. Metallographic examination was therefore conducted in order to obtain further information as to the nature and extent of the damage to this plate. Test sections were cut from different areas of the plate, mounted and prepared for metallographic examination.

Different forms of damage were observed. These included; pitting of the interior surface of the vessel plate as shown in Figure 2. In some cases cracks were observed originating from the pitted regions, Figure 3. Microcracks were also found inside the plate thickness, near the interior surface of the plate, Figure 4. In most cases these cracks were of the stepwise type cracking along the rolling direction of the steel. Cracks on one plane tended to link up with cracks on adjacent planes to form "steps" across the thickness, similar to that shown in Figure 5.

A further form of damage that was observed was internal voids or cavities of a somewhat rounded shape similar to that shown in Figure 6. It seems that these voids contained very high hydrogen pressure as indicated by the deformed grains surrounding the voids. As a result of the high pressure, the voids interconnected to form long cracks as illustrated by the photographs of Figure 7.



(a)

(b)

Fig. 2: Microsection through pitted region on the interior wall of the pressure vessel. 50X, (a) Unetched (b) Etched

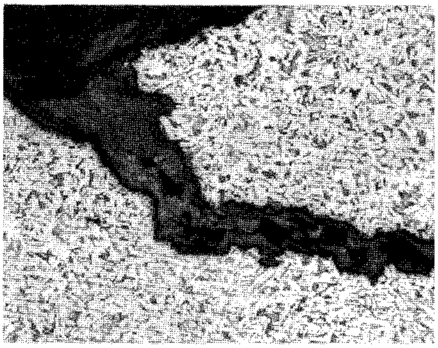


Fig. 3: Cross section of plate showing crack originating from pitted region. 100X

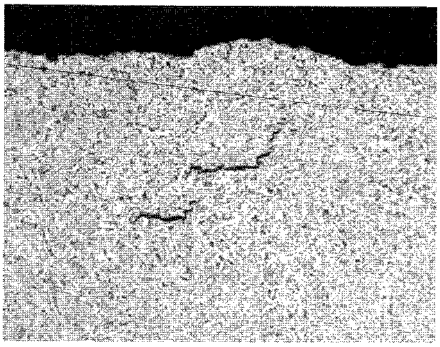
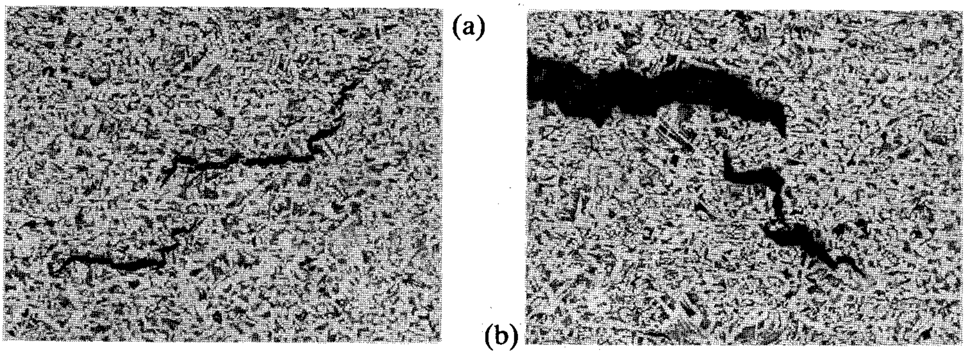


Fig. 4: Microcracks forming near the interior surface of the pressure vessel, 50X



(a)

(b)

Fig. 5: Typical forms of stepwise cracking. Etched. 100X.

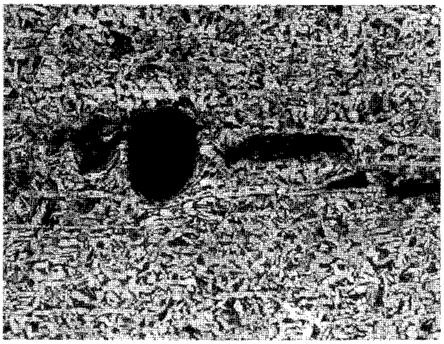
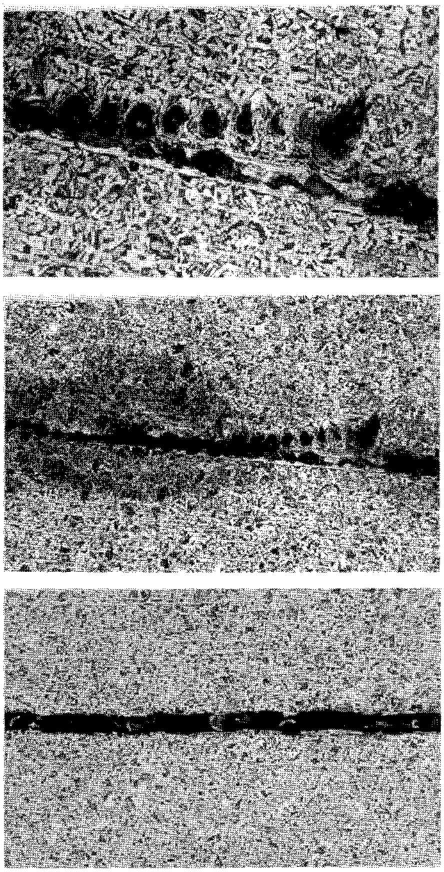


Fig. 6: Cross sections of the plate showing large void due to hydrogen blistering. 100X
Note: Void surrounded by deformed grains



(a)

(b)

(c)

Fig. 7: Cross section of the plate showing void formation and interconnection to form a long crack. (a) 100X, (b) and (c) 50X

Tensile Testing

Four plate samples were machined from the vessel plate, two samples in the longitudinal direction and the other two in the circumferential direction. Tensile tests were carried out using a 600 KN universal testing machine. The results are summarized in Table 1.

Impact Testing

Four samples were machined from the vessel plate, two in the longitudinal direction and another two in the circumferential direction. Impact samples were 10 by 10 mm in cross section with 2 mm V notch. All samples were taken from the mid-thickness of the plates.

The results of impact testing are shown in Table 2.

Table 1

Tensile Test Results for the Pressure Vessel Material

a) Longitudinal Direction

Sp. #	Sy (MPa)	UTS (MPa)	Elongation
1	316.8	410.1	7.5%
2	313.4	504.6	8.6%
Average	315.1	457.35	8.1%

b) Circumferential Direction

Sp. #	Sy (MPa)	UTS (MPa)	Elongation
1	314.3	548.6	30%
2	316.8	550.7	30%
Average	315.6	549.7	30%

Table 2

Impact Test Results for the Plate

Direction	Specimen # 1	Specimen # 2	Average
Longitudinal	31.5	32	31.75 J
Circumferential	201.4	73	137.2% J

Hardness Determination

Hardness measurements were carried out using Rockwell hardness tester. Impressions were made on longitudinal and circumferential sections of the plates in order to detect any variation in hardness in both directions. A load of 60 kg was applied and ten readings were taken on each specimen. The average hardness was 45.4 Ra in longitudinal direction and 45.7 Ra in circumferential direction.

DISCUSSION OF RESULTS

The general microstructure of the plates consisted essentially of ferrite and pearlite grains. The grains were severely deformed in circumferential direction, Fig. 1(a), compared with the randomly oriented grains in the longitudinal direction, Fig. 1(b). This indicates that rolling was made in the circumferential direction of the pressure vessel. This conclusion was further confirmed by the higher ductility and ultimate tensile strength observed in the circumferential direction of the plate. The average UTS value in the circumferential direction was 550 MPa while that in the longitudinal direction was 457 MPa. Ductility, measured as elongation percent, was 30% for the circumferential direction and only 8% for the longitudinal direction. It is worth noting that the UTS and ductility for the plate in the longitudinal direction are less than the specified ASTM values (485 MPa and 30%, respectively) while the yield strength conforms to specifications. Impact test results also indicate that the impact strength in circumferential direction (137J) is much higher than that in the longitudinal direction (32J). This is in agreement with the results of the metallography and tensile testing. Hardness testing did not reveal a significant difference in the hardness in both directions.

While preliminary metallographic examination was conducted in order to determine the nature and extent of the damage in the pressure vessel it is believed that further useful information could be obtained by conducting a more systematic metallurgical study and relating the results to those obtained by the NDT technique in order to determine a suitable and reliable failure criterion for such pressure vessels.

CONCLUSIONS

1. The pressure vessel had elongated grains and superior tensile and impact properties in circumferential direction compared with the longitudinal direction.

2. The UTS and ductility of the pressure vessel in the longitudinal direction are less than the specified ASTM values.

3. Rolling direction of the pressure vessel was found to be in circumferential direction of the pressure vessel.
4. Extensive damage was observed in the pressure vessel which had been in service for over 23 years. This includes: pitting, hydrogen induced cracking and blistering.
5. Further study using non-destructive testing techniques is required in order to determine a suitable and reliable failure criterion which may extend the safe service life of such pressure vessels.

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