Brittle Fracture of Hydrodesulfurization Reactor during Pressure Test

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(Summary)

The reactor of the hydrodesulfurization plant for light oil, naghtha and kerosene failed during the hydrostatic test using N_2 before the restart-up after scheduled shutdown inspection(Fig. 1, 9,000BPD).

The plant had worked for 21 years before the accident but the service time of the reactor was 16.5 years, and its operation conditions were ～50kgf/cm^2(hydrogen partial pressure; ～39kgf/cm^2) and ～350℃. The reactor was fractured into 44 pieces(the heaviest one; 4,600kg) which gave severe damages to the equipment, pipings and structures around the reactor. But no casualty was counted because the accident occurred midnight.

1. Component

Reactor of desulfurizantion process(Fig. 2, 89t pressure wall of SB46M + 3.5t clad of SUS405)

2. Event

On March 1st, 1980, No.2 hydrodesulfurizaion plant was normally shut down and as to its reactor, applied were small modification work for increasing catalyst holding as well as normal scheduled inspections. After loading new catalyst, the hydrostatic test of the reactor was started using liquid N_2 tank truck at 10:30 on April 1st, 1980. At 23:55 when the pressure of the reactor reached its regulated test one, the accident occurred.

3. Course

The 44 pieces of the fractured reactor were collected and the map of fracture-pieces was made as shown in Fig. 3 where the arrows indicate the crack propagation directions. Based on the analysis results of Fig. 3 and the distribution of the catalyst blown out of the reactor, the starting point of fracture was presumed at (a) in Fig. 3.

Examination of fracture surface, microstructure analysis, electron probe micro analysis (EPMA), chemical analysis of (a) were carried out and it was concluded that the starting point was within the weld repaired part applied during fabrication of the reactor at shop.

The story of the repair work at shop was supposed as follows; In the nondestructive inspection of weld lines after completion of welding, found were defects in the circumferential weld line of the reactor. The defects were ground off and repair welding with D309 was applied. Finally, the inner surface of the repaired part was weld over laid with CR40Cb for matching the SUS405 clad (Fig. 4, 5).

4. Cause

The main cause of the accident was that the maintenance team in charge of the reactor failed to anticipate (1)disbonding of base metal and repair weld metal and (2)hydrogen attack of base metal.

The progress of damage was presumed as follows;

Due to the repetition of plant startup and shutdown for many years, disbonding at the boundary of C-0.5Mo steel and D309(Dissimilar weld joint) occurred and worked as the starting point of crack(Fig. 4 I ～IV). After the crack propagated and reached the inner surface of the reactor(Fig. 5 (A)), hydrogen attack of base metal occurred at the disbonded area and propagated toward the external surface of the reactor(Fig. 5 (B)). When the stress intensity factor of the crack tip reached the fracture toughness of the base metal under the hydrostatic test condition(wall temperature; 13℃, pressure; 55kgf/cm^2), the accident occurred.

[Disbonding of Dissimilar weld joint]

There was no report of disbonding of C-0.5Mo steel-D309 dissimilar weld joint at hydrodesulfurization reactors for light oil in 1970's. But there were several informations about disbonding of ferrite-austenite dissimilar weld joint at heavy oil desulfurization reactors, although it was early 1980's that the detail reports on it were published. Therefore, it should have been anticipated the disbonding in this accident, although it should have been quite hard.

[Hydrogen attack of C-0.5Mo steel]

When we decide the operating conditions of equipment processing hydrogen at elevated temperature and pressure, it is the general practice to use API 941 for preventing hydrogen attack of steel. The API 941 being used in April, 1980 was API 941-1977 edition, and suggested that the operating conditions of the fractured reactor were in its safe region. Since 1977, however, there had been information and communications to API of plant experiences involving hydrogen attack of C-0.5Mo steel in the safe region of 1977 edition, although it was 1983 that API officially referred to the attack in safe region.

5. Countermeasure

In situations in which hydrogen handling equipment of C-0.5Mo steel has been operated at elevated temperature and pressure, rigorous periodic inspections should be carried out, where the inspection techniques are required to be detectable defects within wall.

It is the general way to apply austenitic weld metal like 309 so as to avert PWHT when we carry out repair welding of equipments of C-0.5Mo steel. In case that the equipment repaired by this way is used under the conditions having hydrogen attack possibility, the practices of their periodic inspections should be discussed in detail and understood by all members concerned. A lot of inspection methods using ultrasonic techniques have been developed for detecting hydrogen attack of pressure vessels.

6. Knowledge

There are many standards for selecting construction materials of plants, which are based on plant experiences like API 941(Especially, standards for environmental embrittlement like stress corrosion cracking, hydrogen embrittlement, etc.).

When those standards are used for design, the owner of the plant as well as the people who were concerned in design, fabrication and construction should not neglect following up the information about the standards through out the plant life.

7. Primary Scenario

01. Unknown Cause
02. Occurrence of Unknown Phenomenon
03. Disbonding of ferrite-austenite weld joint under high temperature and high hydrogen pressure
04. Insufficient Analysis or Research
05. Insufficient Prior Research
06. Overconfidence in API 941
07. Usage
08. Maintenance/Repair
09. Unsuitable Inspection Method
10. Failure
11. Fracture/Damage
12. Disbonding of Ferrite-austenite Weld Joint
13. Hydrogen Attack of C-0.5Mo Steel
14. Failure
15. Large-Scale Damage
16. Fracture of Reactor
17. Partial Fall Down of Desulfurization Plant

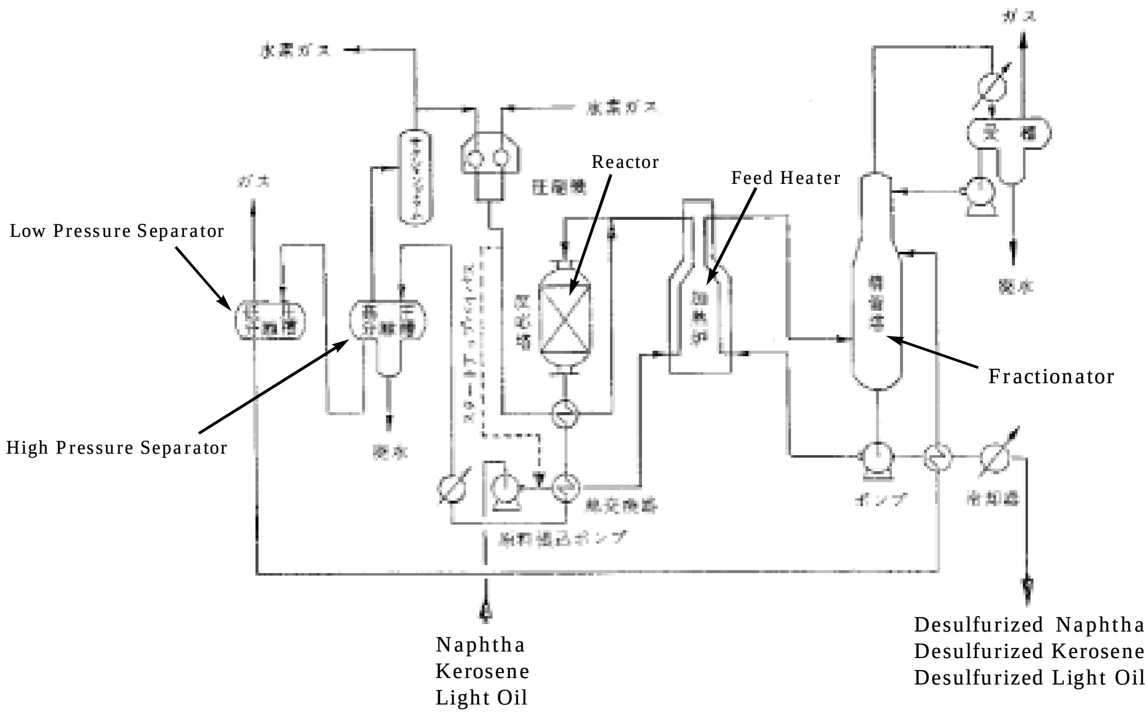
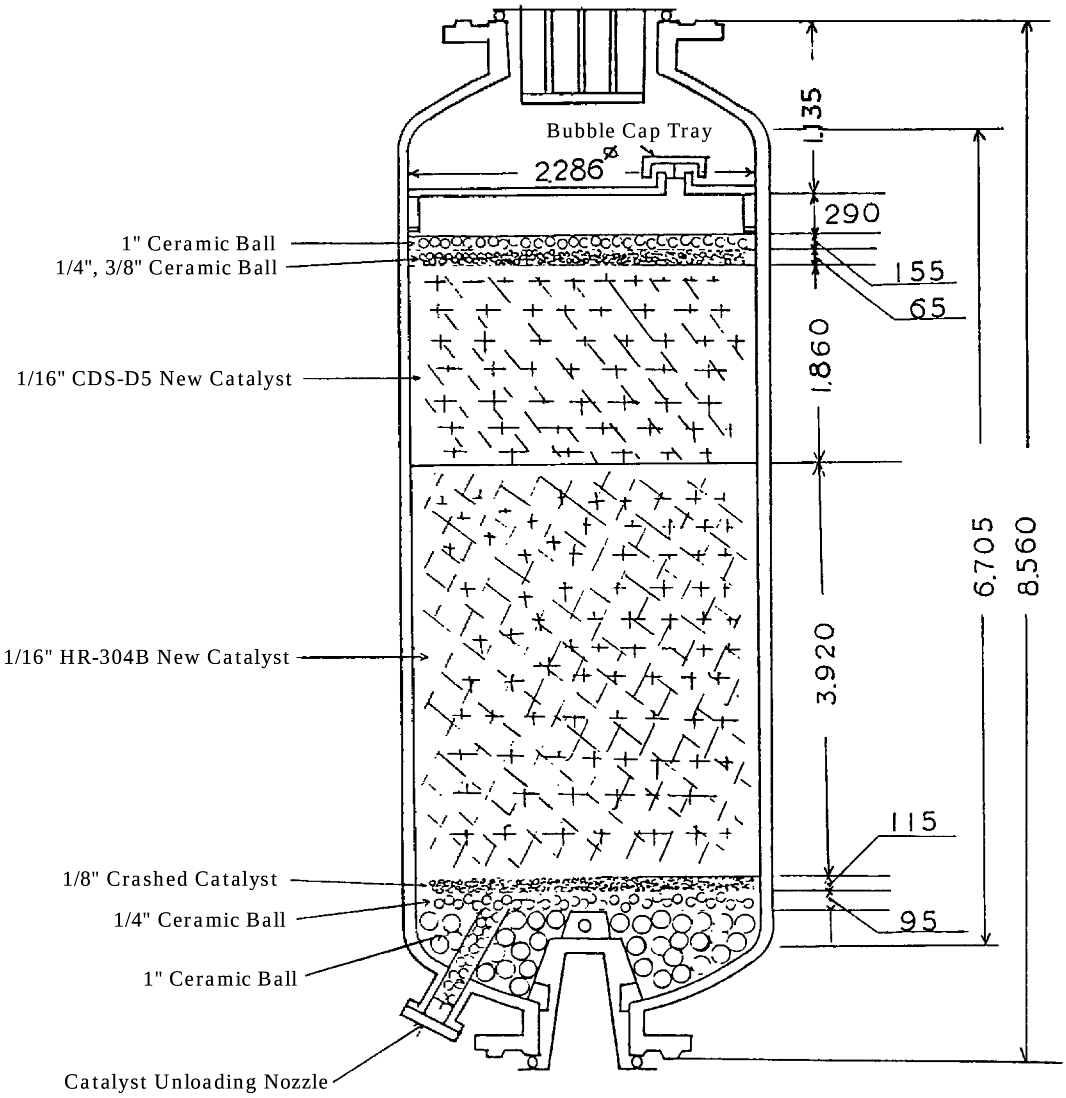


Fig. 1 Flow Sheet of Hydrodesulfuraization Plant.



Total Volume : $31.0M^3$
Catalyst Bed Volume : $23.7M^3$

Fig. 2 Structural Sketch of Hydrodesulfuraization Reactor.

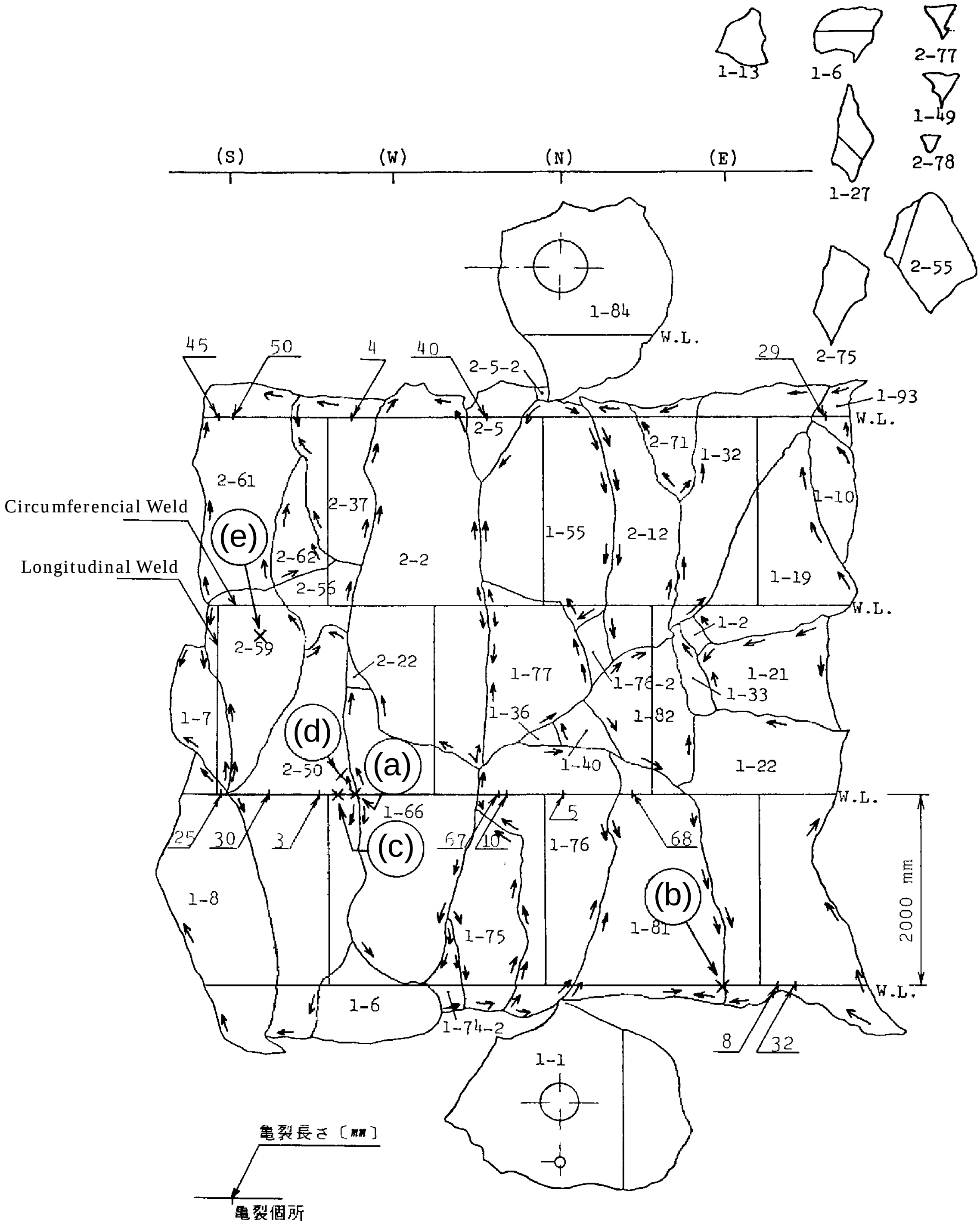


Fig. 3 Map of Fractured pieces of Reactor.

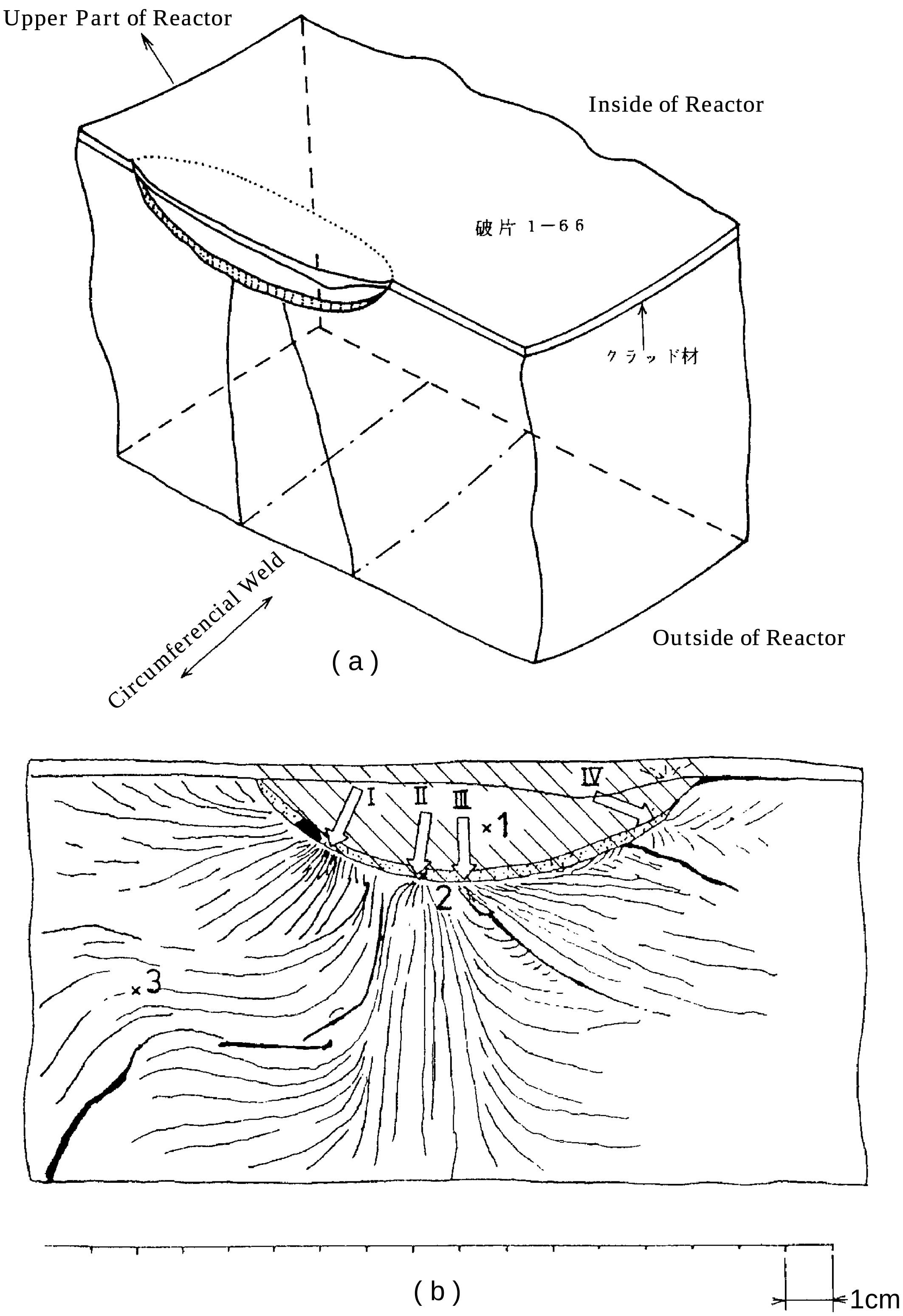


Fig. 4　Schematic Representation of Fractured part weld repaired at shop.

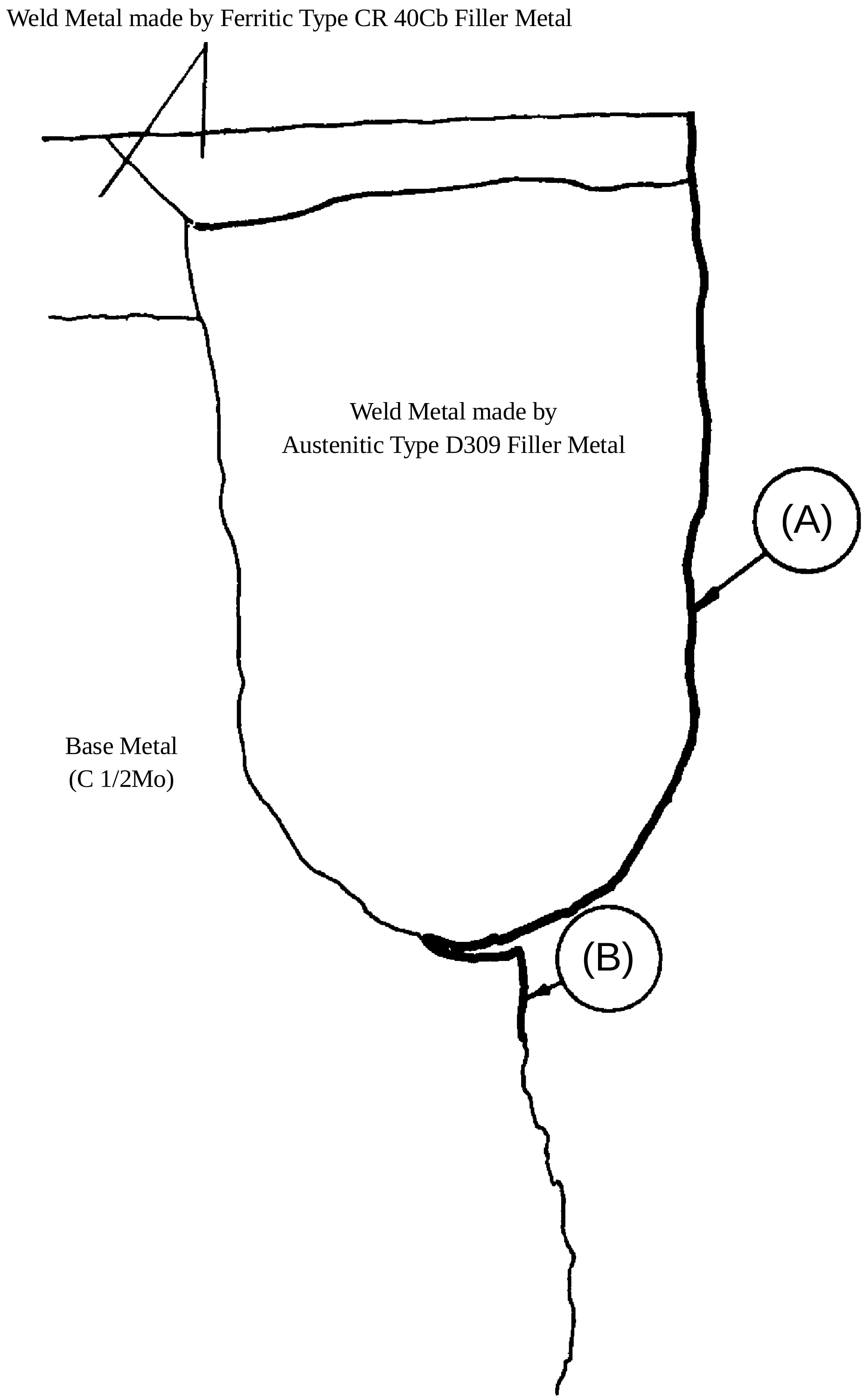


Fig. 5 Schematic Representation of Crack Propagation.