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Original Paper

# System for Simulating the Embrittlement induced by Creep in Steel Weld

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Welded Zones of some Cr-Mo steels are susceptible to the embrittlement when their weldments are used for high temperature services. This embrittlement appears as the phenomena of the low-ductility creep-fracture (LDCF), and the temper-embrittlement induced by creep (TEIC). A system which reproduces those phenomena in laboratory was proposed in this paper. This system was composed of the simulator of weld-thermal-cycle and the machine for creep-loading. The methods and conditions for using this system were discussed in detail. Some experiments on the LDCF of 1 1/4Cr-1/2Mo steel proved this system to be very useful for the investigations of the LDCF and TEIC.

Key Words: creep fracture, temper-embrittlement, reproduction of embrittlement, simulated-HAZ, creep-test machine, 1 1/4Cr-1/2Mo steel.

## 1. Introduction

Heat-resisting low-alloyed steels have excellent creep-resisting properties in the medium temperature range, and are applied widely for boilers and vessels. However, it is pointed out recently that some welded zones of Cr-Mo steels, such as 1 1/4Cr-1/2Mo steel, are embrittled under certain service conditions. This embrittlement appears as the phenomena of (1) "the low-ductility creep-fracture" (briefly shown hereafter as LDCF) in the operating time [1,2,3], or (2) the rise of transition temperature, which is recognized at room temperature [4]. The latter may be "the temper-embrittlement induced by creep" (briefly shown as TEIC). However, the factors affecting those phenomena and the processes of inducing them are not yet revealed, and a series of detailed investigations will be required to clarify all of them.

In this paper, a basic system for reproducing LDCF and TEIC in laboratory is introduced. This system is composed of the simulator of weld-thermal-cycle and the machine for creep-test. The latter is used for the creep-rupture test in case of LDCF; and for creep-loading in order to prepare the impact-test specimen in case of TEIC. Some results obtained by this system were explained on the LDCF of 1 1/4Cr-1/2Mo steel.

The term of "creep embrittlement" [1,3] or "creep cracking" [2] has been given to the phenomenon corresponding to LDCF. However, these terms will not denote this phenomenon adequately or correctly. Then, the authors adopted the term, LDCF in this paper.

## 2. Apparatus and method for simulating HAZ microstructure

The best way to examine the LDCF and TEIC would be to test the HAZ portion directly. This portion, however, is too narrow to be tested by itself. Then the HAZ microstructure was reproduced all over on a steel bar by the simulator of weld-thermal-cycle and it was subjected to the creep-rupture test or the creep-loading followed by impact test.

The simulator of weld-thermal-cycle made by Fuji Electronic Industrial Company was used. The construction of this simulator is shown schematically in Fig.1. The specimen set in the coil is heated by HF current supplied by the HF generator (the maximum output of 15 kW with 70 kHz); after its temperature reached an ultimate one, it is quenched by nitrogen gas or water flowing out from the coil. Optional heating- and cooling rates are programmed and given by a temperature-controlling unit.

1 1/4Cr-1/2Mo steel plate (JIS SCMV3) shown in Table 1 was used for experiments. A steel bar of 7 x 12 x 60 mm was machined from the plate taking its length parallel to the rolling direction.

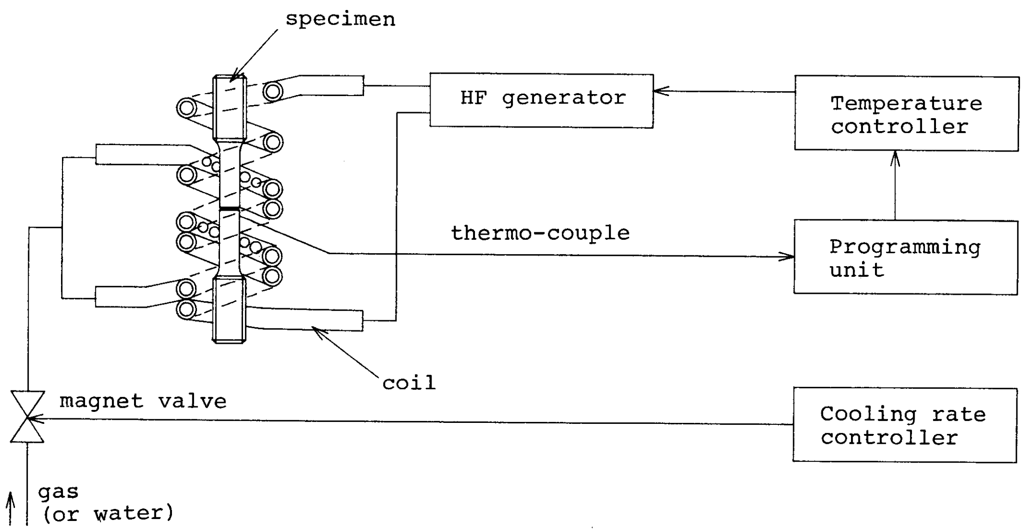



Fig.1 Simulator of weld-thermal-cycle

A weld bead was deposited on a plate of 11 mm in thickness by the manual arc welding with the heat input of 18 kJ, and the microstructure of coarse-grained-zone in HAZ was observed. This microstructure was reproduced in the steel bar by using the simulator with the following conditions which were obtained from some preliminary examinations.

1) Maximum temperature: 1350 C, 2) Time for heating up to 1350 C: 14 sec,
3) Time for cooling from 800 to 500 C: 14 sec.

The microstructure of simulated-HAZ specimen is shown in Fig.2(a). It is composed of martensite (white lath) and bainite (lath containing fine particles). This microstructure resembles well that of the grain-coarsened-zone in natural-HAZ shown in Fig.2(b). The hardness of the former (Hv 359) is also close to the latter (Hv about 365).

3. Apparatus for creep-loading

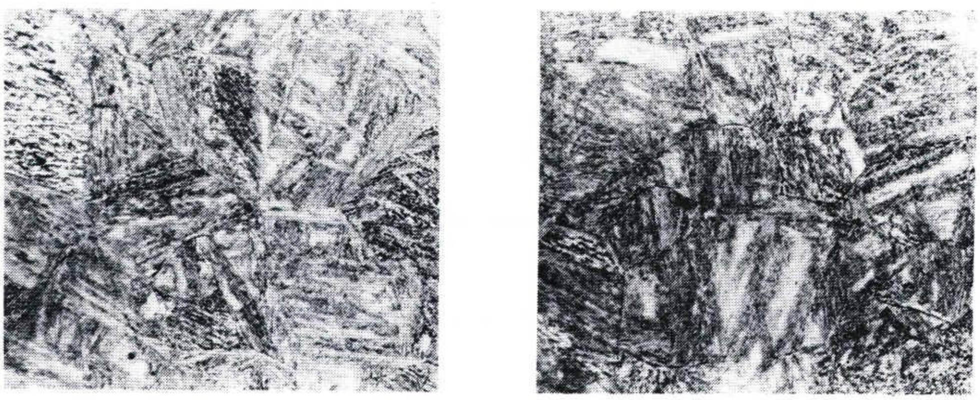
A lever-type creep-test machine with loading capacity of 2 ton shown in Fig.3 was constructed by the authors. Details of the furnace and fixtures of specimen are shown in Fig.4. A recorder and regulator of the temperature were connected with AC-thermocouples which were welded onto the specimen. The elongation during creep-loading was estimated by the displacement of the fixture which is measured by a differential transformer.

After a given stress was loaded, the temperature of specimen was raised up to a test temperature. In case of the examination of LDCF, the specimen was

Table 1 Chemical composition of 1 1/4Cr-1/2Mo steel plate

| C | Si | Mn | P | S | Cu | Ni | Mo | Cr | As |
|---|---|---|---|---|---|---|---|---|---|
| 0.15 | 0.06 | 0.75 | 0.005 | 0.003 | 0.01 | 0.03 | 0.52 | 1.40 | 0.002 |

(wt%)



(a) Natural-HAZ (b) Simulated-HAZ

50μm

Fig.2 Microstructures of simulated-HAZ and natural-HAZ (etched by nital) kept at this temperature until it fractured. In case of TEIC, the creep-loading was stopped at a given time period, and the specimen was examined around the room temperature by Charpy-impact test.

4. Test results of LDCF

The creep-rupture test was carried out on the simulated-HAZ and the base metal specimens of 1 1/4Cr-1/2Mo steel. The size of the specimen is shown in Fig.5.

The relation between the stress (S) and the time to fracture (t) tested at 873 K is shown in Fig.6. Logarithmic scales are taken for both the ordinate and the abscissa. Two S-t lines intersect each other at the stress of 215 MPa. In

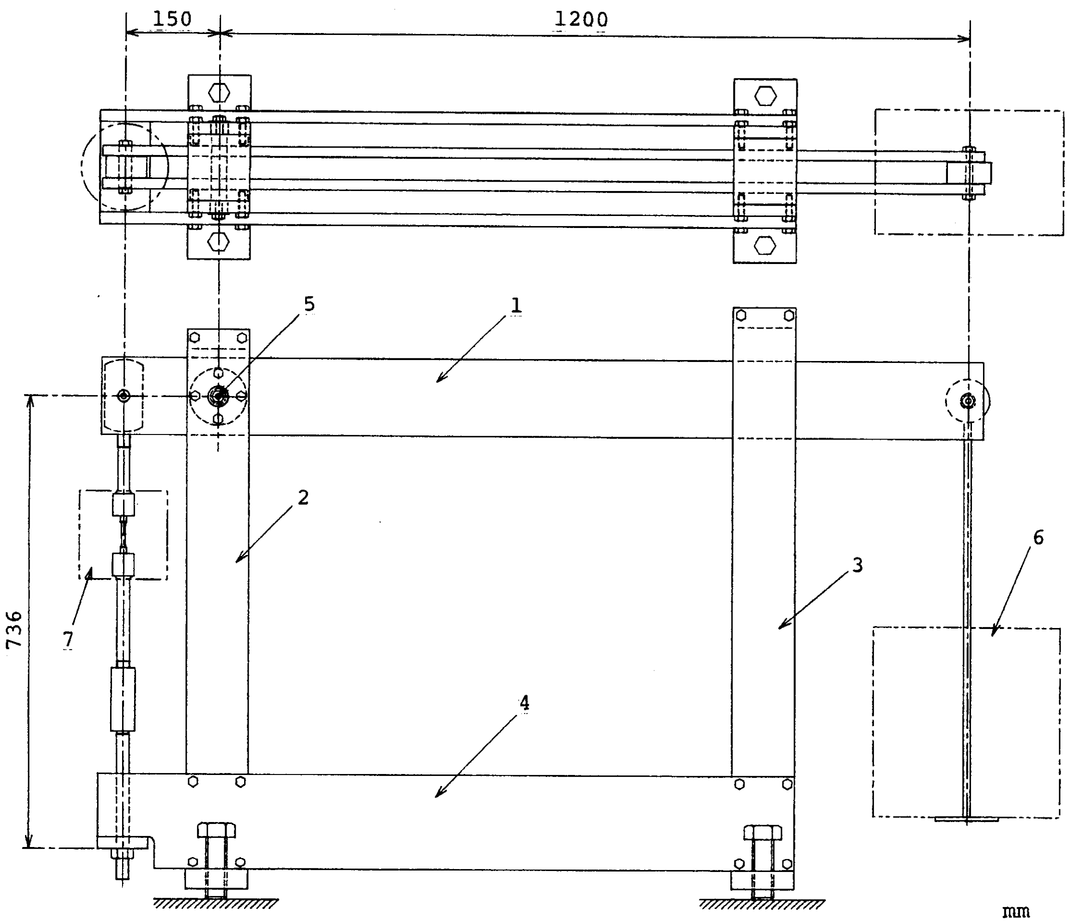
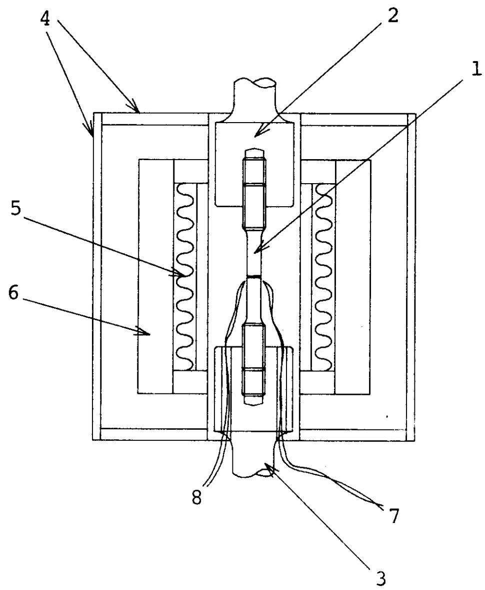



Fig.3 Creep-test machine for LDCF and TEIC
1. lever, 2,3. posts, 4. beams
5. pivot, 6. weight, 7. furnace



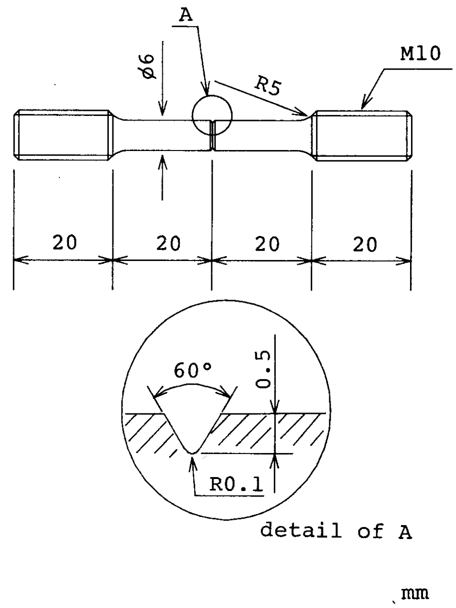




Fig.4 Details of furnace and fixtures
1. specimen, 2,3. fixtures
4. stainless steel covers
5. heating wire, 6. refractory
7,8. AC thermo-couples

Fig.5 Specimen for creep-rupture test

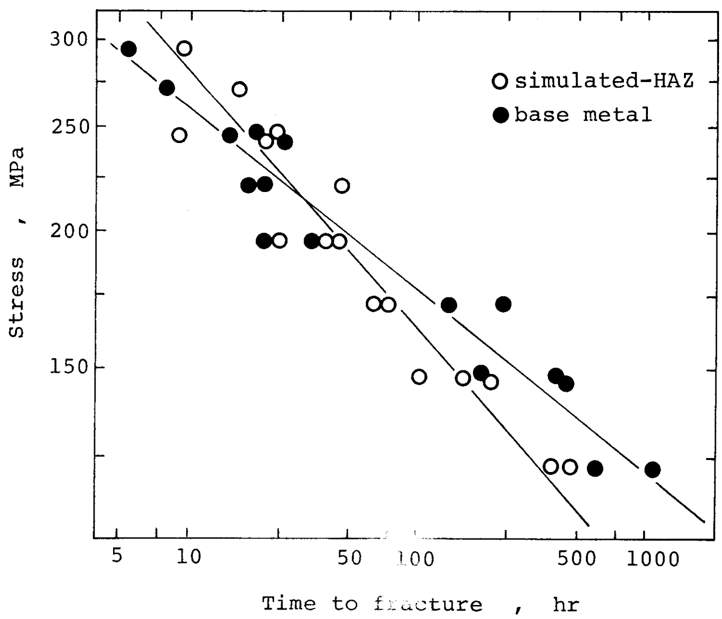



Fig.6 Results of creep-rupture test on simulated-HAZ and base metal of 1 1/4Cr-1/2Mo steel

the higher stress range, base metal specimens fracture with shorter lives than HAZ specimens do, and in the lower stress range, vice versa. Nevertheless, the difference of lives between two lines is smaller, and therefore, the nature of LDCF is recognized little on the S-t line itself.

The reduction in area (RA) was measured on each specimen as shown in Fig.7(a) and (b). They inform that (i) RA values of HAZ specimens are extremely small regardless of the stress level and the time to fracture, (ii) base metal specimen fractured in shorter time under a higher stress level show larger RA values, but RA decreases with an decreasing stress, and hence, an increasing life.

Fractured surfaces of the specimens were observed by a scanning electron microscope. The oxide film adhering on the surface was removed by washing in 0.3N HCl with an ultrasonic vibration for 600 sec at 273 K, and rinsed by water.

The fractured surface of simulated-HAZ specimen exhibits an intergranular decohesion mode; some examples are shown in Fig.8(a) and (b). The grain boundary surfaces in the photos are smooth in appearance if some etch-pits are neglected. Those surfaces will correspond to the grain boundaries of prior-austenite [5]. On the contrary, the fractured surface of base metal specimen shows a dimple rupture mode as the result of a significant deformation, as shown in Fig.8(c) and (d).

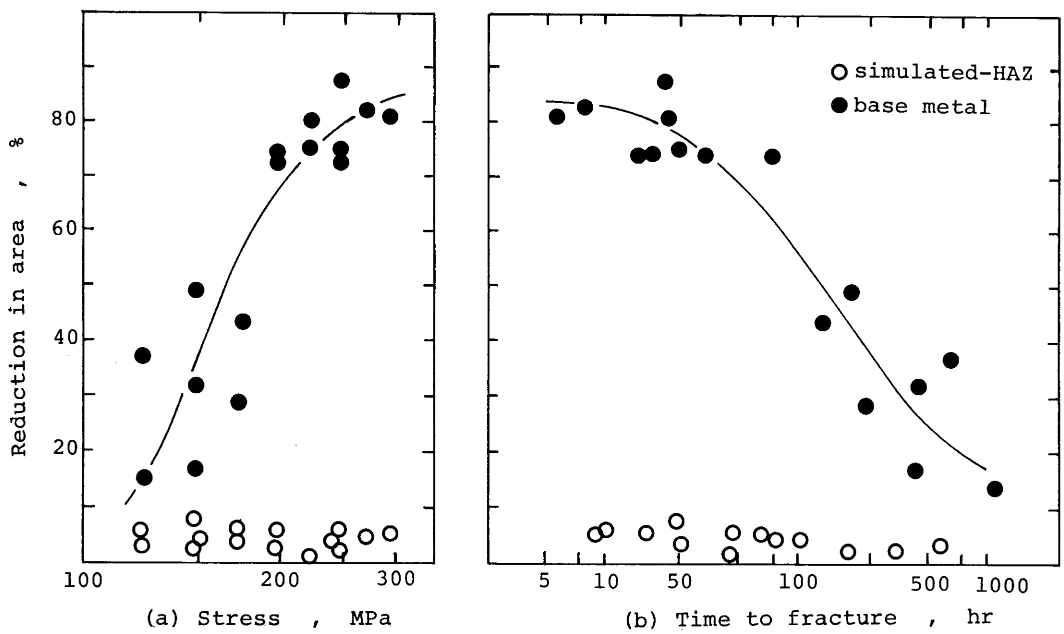



Fig.7 Reduction in area shown by the parameters of stress (a) and time to fracture (b)

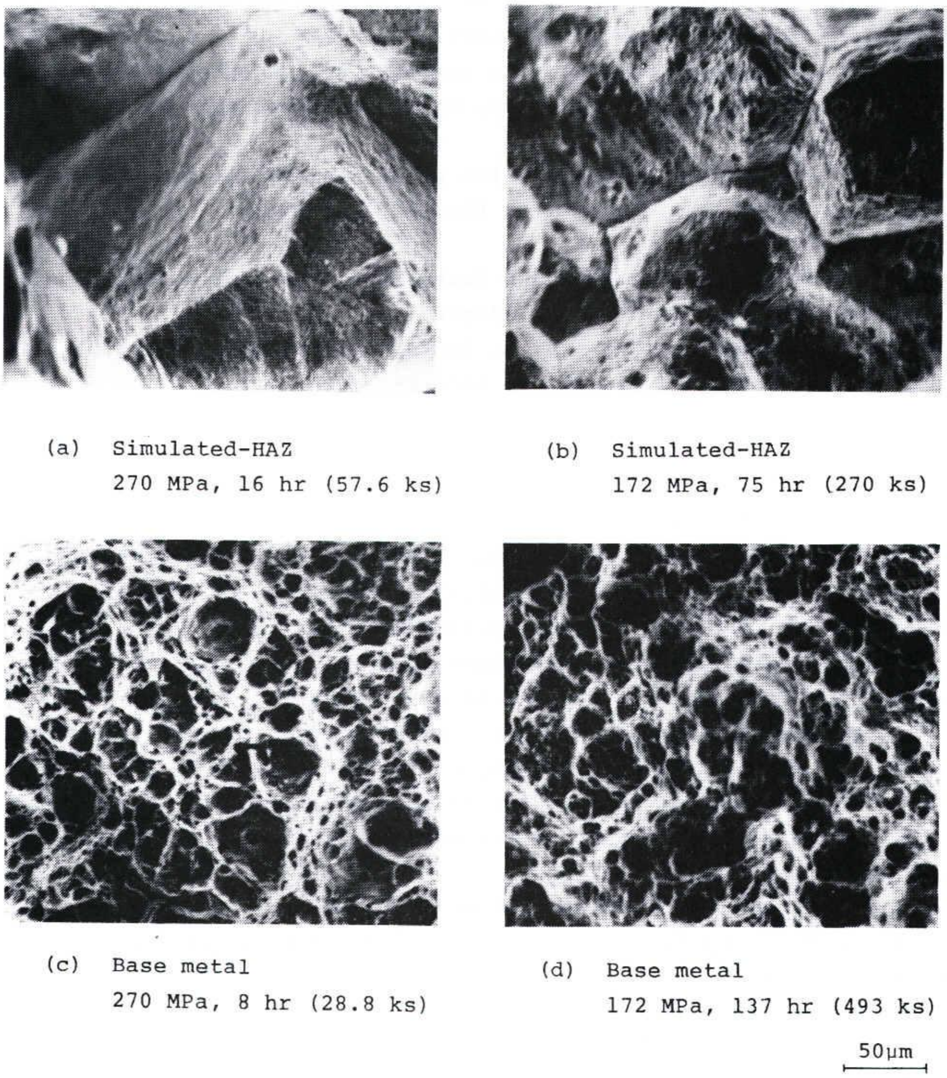
## 5. Discussion on the results

Those results of the occurrence of intergranular fracture in the HAZ support well the following concept on phosphorus segregation which was introduced by the authors in the preceding reports [5,6].

(a) Initiation of segregation: Phosphorus is segregated in austenite grain boundary by the rapid-heating process in the weld-thermal-cycle [5].

(b) Intensification of segregation: Phosphorus segregation initiated by welding is intensified further by reheating in a critical temperature range of 750 to 850 K [5,6].

(c) Contribution of stress: The stress increases significantly the concentration of phosphorus in the grain boundary [6].



(a) Simulated-HAZ 270 MPa, 16 hr (57.6 ks)

(b) Simulated-HAZ 172 MPa, 75 hr (270 ks)

(c) Base metal 270 MPa, 8 hr (28.8 ks)

(d) Base metal 172 MPa, 137 hr (493 ks)

50μm

Fig.8 Fractured surfaces of specimens obtained by creep-rupture test

(d) Segregation and cracking: The intergranular cracking at the prior-austenite grain boundary occurs when its phosphorus concentration reaches a critical value [6].

It is expected that a further systematic examination on LDCF and TEIC in a wide temperature range will reveal whole natures and detailed mechanisms of those phenomena.

## 6. Conclusions

(1) An experimental system which reproduces the low-ductility creep-fracture (LDCF) and the temper-embrittlement induced by creep (TEIC) was proposed. It is composed of the simulator of weld-thermal-cycle and the creep-loading machine.
(2) The LDCF of 1 1/4Cr-1/2Mo steel was examined by this system. The simulated-HAZ specimen fractured with very small reduction-in-area and the fractured surface exhibited an intergranular decohesion mode; this fracture mode reproduced well the nature of the LDCF.
(3) This result on the LDCF supports the concept that phosphorus segregating in the grain boundary weakens the latter, which was proposed by the authors previously.
(4) This system will enable to clarify the whole natures and mechanisms of the embrittlement of Cr-Mo steels including the LDCF and TEIC.

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