F12/4

Mechanical Behaviour of the HAZ in Reactor-Pressure-Vessel-Weldments Before and After Irradiation

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ABSTRACT

For each pressure vessel of light water reactors a surveillance program is required, which includes besides base metal- and weld metal- also HAZ-specimens from the core-weldment. Due to the steep gradient of properties in the HAZ, special test techniques have been developed. By those it could be demonstrated that the HAZ-thoughness is better as in the quarter thickness location of the base metal.

1 INTRODUCTION

The pressure vessel is the only safety relevant component in light water reactors with respect to neutron embrittlement. Therefore it is international practice, to require a surveillance program for each individual plant. Several national standards regulate such programs. Basis for this paper is the German standard KTA 3203 "Überwachung der Strahlenversprödung von Werkstoffen des Reaktordruckbehälters von Leichtwasserreaktoren". A comparison with ASTM E185 "Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels" has been published in 1984 /1/. Both standards include impact tests at the HAZ of the core weldment. The long time experience with such tests will be presented.

2 DEFINITION OF THE HAZ

The HAZ of any weldment will be defined as the region between the fusion line and the temperature line, which exceeds the highest heat treatment temperature before welding. In this paper, which deals with quenched and tempered steels of 22 NiMoCr 3 7- and 20 MnMoNi 5 5-type forgings (chemical composition see table 1), it is the temperature range of 1500°C to 680°C. This region is shown in FIG. 1 for a typical submerged arc weldment and has a width of about 3 mm. At least every microstructural and mechanical properties in the HAZ have a steep gradient, as for example grain size, hardness and tensile properties. FIG. 2 and 3 show this for the yield strength, determined with micro specimens at different test temperatures.

3 CONVENTIONAL TESTING OF THE HAZ

KTA 3203 requires Charpy impact tests of the HAZ as sketched in FIG. 4. Although the machining has been done very careful and well documented, about 90 % of the specimens do not break completely within the HAZ. Normally the crack starts in the HAZ and runs then into the base metal or weld metal, depending from their toughness properties. Only in the lower shelf range is a chance for a complete break in the HAZ. The conclusion of this observation is,that the HAZ is tougher than base metal and weld metal. Consequently we should compare only HAZ with base metal, because the weld metal, at least, is not involved.

In conclusion of this results, HAZ-specimens make less sense within surveillance programs. To support this decision, several additional tests have been done.

4 IMPACT TESTS WITH MICRO SPECIMENS

From the a.m. results it seems to be no chance to test the HAZ with standard Charpy specimens. Therefore another test procedure has been adapted, as shown in FIG. 5. From the results will be concluded that the toughness of the HAZ is better than those of the base metal. The somewhat lower USE is negligible. As mentioned before, the weld metal behaviour has not to be taken into account.

5 DROP WEIGTH TESTS WITH INTEGRAL SPECIMENS

For the safety analysis it is important to determine also the NDT-T-temperature. Knowing the difficulties with the smaller Charpy specimens it is hopeless to get meaningfull results from the drop weight tests with much larger specimens.

The meaning of "integral specimens" is shown in FIG. 6. The idea was that the running crack will give some informations about the toughness relations between weld metal-HAZ-base metal. The very first tests confirmed this idea, as shown in FIG. 7, for higher and lower toughness of the HAZ. Similar results have been observed from plant specific surveillance programs in the non-irradiated and irradiated condition.

Although it is difficult to get a defined NDT-temperature from integral specimens, it is very meaningfull to know if the HAZ has better or worse properties as the base metal.

6 TESTS WITH SIMULATED SPECIMENS

Due to the well known difficulties of testing HAZ's, it is common practice to use simulated materials. Impact and drop weight tests, also in the irradiated condition, showed, that the HAZ-simulated specimens have better toughness properties than the base metal. This is to understand by the optimal fast cooling in the HAZ, compared with the lower cooling rate in large forgings at quarter thickness location. In table 2 the results of a basic investigation are listed.

7 CONCLUSIONS

In specific investigations it could be demonstrated that the HAZ of as specified weldments in the reactor pressure vessel has better toughness properties than the base metal. It is therefore to decide if HAZ-Charpy-specimens should be included in the future within surveillance programs.

As an alternative some tests with integral drop weight test-specimens for the non-irradiated condition are recommended with at least only three specimens, tested at

- NDT-Temperature of the base metal
- NDT-Temperature plus 5°C of the base metal
- NDT-Temperature plus 10°C of the base metal.

From the present experience, one should get similar results, as demonstrated in FIG. 7. If not, additional investigations are recommended.

REFERENCE

Ernst,K.R., Klausnitzer,E. and Leitz,C. (1984). Safety Standard KTA 3203: Monitoring Radiation Embrittlement of Reactor Pressure Vessels of Light-Water Reactors. IAEA Specialists Meeting Wien, STP 909, pp.177-183.

Material	Chemical composition, wt. %							
	C	Si	Mn	P	S	Cr	Mo	Ni
22 NiMoCr 37-forging	0,17-0,25	0,15-0,35	0,50-1,00	≤0,015	≤0,015	0,25-0,50	0,50-0,75	0,60-1,00
20 MnMoNi 55-forging	0,17-0,25	0,15-0,30	1,15-1,50	≤0,012	≤0,015	≤0,20	0,45-0,60	0,40-0,80

Table 1: Chemical Composition of the test materials

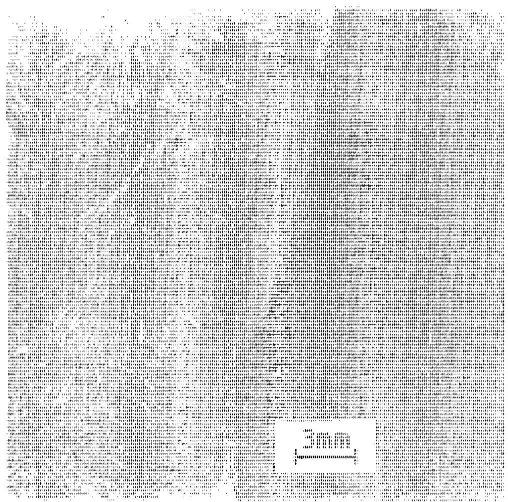


FIG. 1: Typical HAZ of a submerged arc weldment

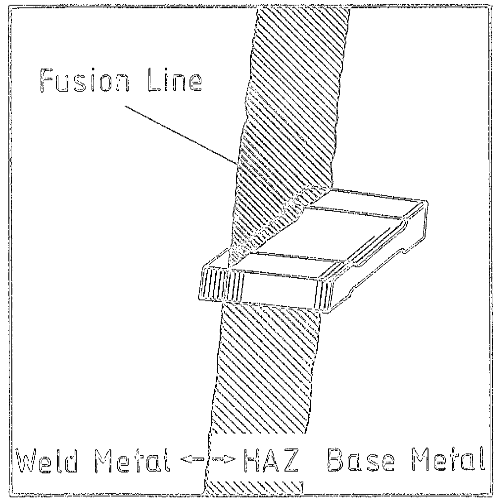


FIG. 2: Orientation of micro tensile specimens for HAZ-investigations

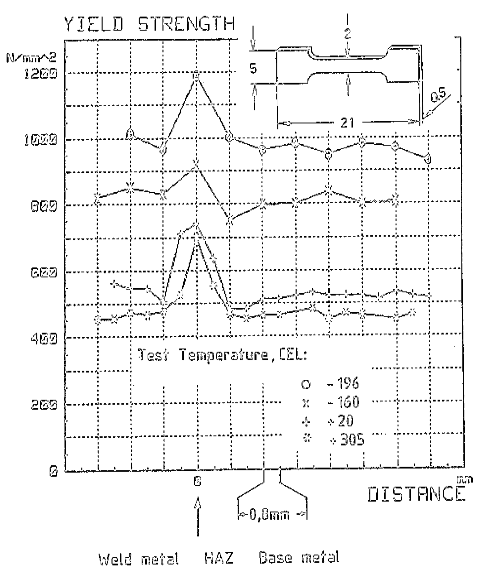


FIG. 3: Yield strength across a weldment at different temperatures

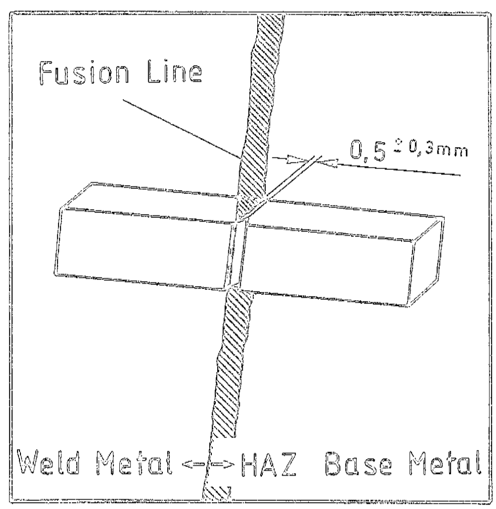


FIG. 4: Location of Charpy specimens in the HAZ

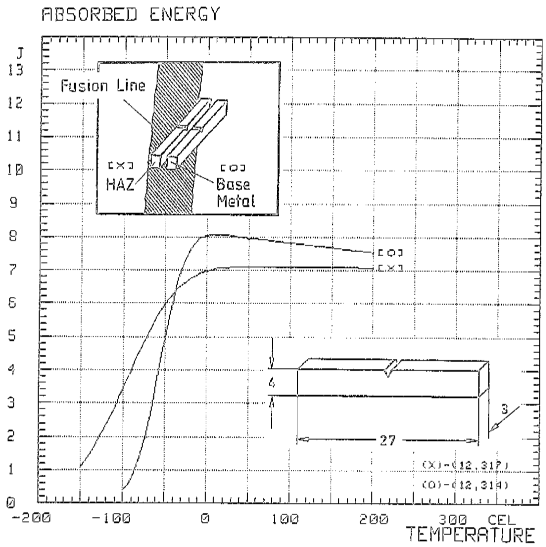


FIG. 5: Determination of HAZ-toughness with micro impact specimens

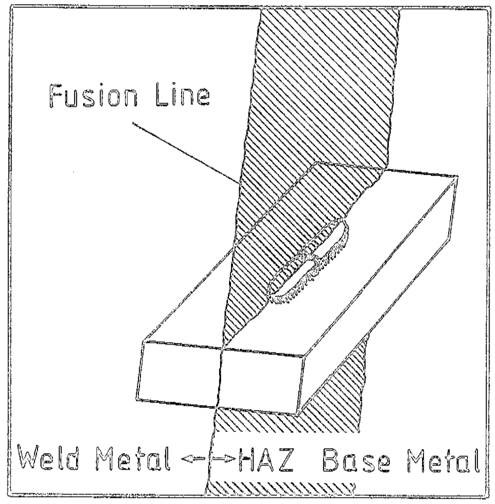
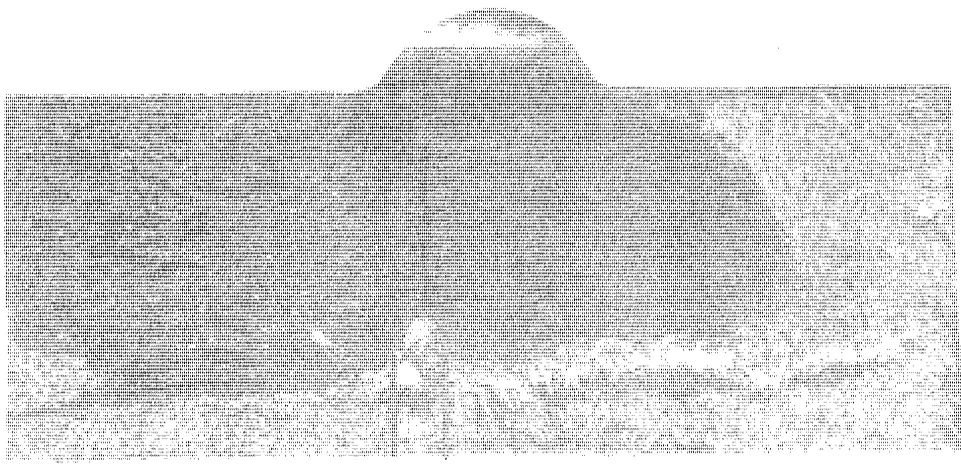


FIG. 6: Location of P-2 drop weight specimens for integral HAZ-tests

Material	Condition	T41J, °C	NDT-T, °C
22 NiMoCr 37	quenched and tempered	-49	-25
non irradiated	HAZ-simulated	-88	-75
22 NiMoCr 37 2xE19 n/cm^2	quenched and tempered	-20	+17
(E > 1 MeV)	HAZ-simulated	-30	-32

Table 2: Comparison of results from base metal- and HAZ-simulated specimens



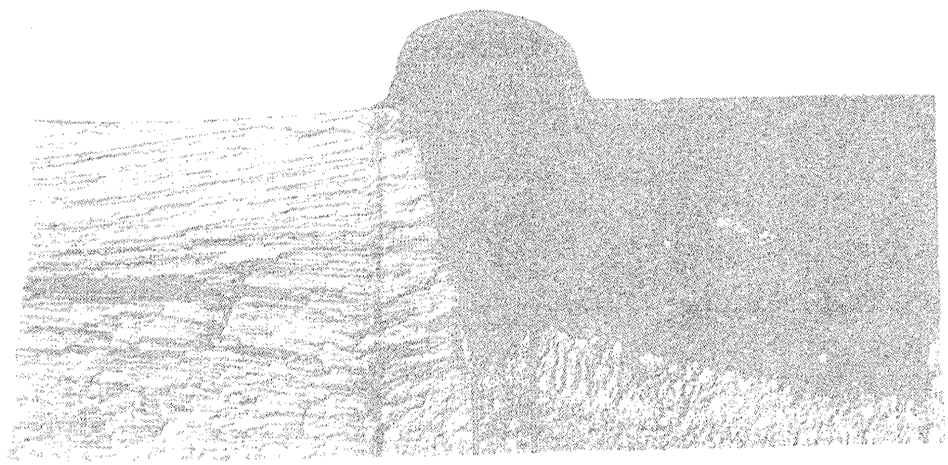


FIG. 7: Comparison of results from integral drop weight tests at weldments with P-2 specimens

(Test procedure: After the drop weight test itself, the specimens have been heat tinted at 300°C and broken at -196°C)