Study of Crack Initiation - Arresting Conditions in Plane Plates and Cylindrical Model Vessels

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An extension research effort has been performed at Škoda-Works, Pilsen, Czechoslovakia, for studying safety criteria in nuclear reactor pressure vessels. Following problems have been specially considered :

a) Analysis of the correlation between test of crack initiation and of arresting conditions on plane plates (uniaxial stress fiels) and cylindrical pressure vessels (biaxial stress fiels).
b) Analysis of the influence of energy accumulated in pressure vessels on initiation, propagation and arresting of a fracture.
c) Comparison of different types of materials from the point of view of initiation, propagation and arresting of a brittle crack.
d) Analysis of the relationship between brittle fracture characteristics determined on small specimens and on model pressure vessels.
e) Comparison between calculated (on the basis of K_{IC} values and pressure vessel geometry) and found critical defect sizes for crack initiation.

In the 1st series of testing 5 model vessels having diameter 1,200 mm, cylindrical part length 900 mm, wall thickness 30 mm and made from A 302 B type of material in normalized and tempered conditions, were tested. In the 2nd series of testing 4 model vessels having diameter 1,200 mm, cylindrical part length 1,700 mm, wall thickness 30 mm and made from A-542 type of material in quenched and tempered conditions, were tested. Vessel wall profile is shown in lower part of Fig.3 and a photograph of a vessel, prepared for testing, is in Fig. 5.

An axial temperature gradient from -100 to +80 deg C was created in model vessels, the brittle crack being initiated by through-going notch or by thin surface notch. As a pressurizing medium water and/or mixture of water and 20 to 40 vol.% of air was used. Water was pumped into special tank inside pressure vessel and thus isolated from vessel wall. Typical temperature gradients for 2nd series of testing are shown in Fig.3, where crack velocities in plane plate and in pressure vessel are plotted together.

Tests of vessels were completed by testing of plane plates having the same thickness (30 mm) and width of 1,000 mm, loaded by uniaxial tension; the cracks being initiated partly statically from a centric notch, partly dynamically by lateral impact (ESSO type test). In this complementary program also tests of small specimens : Charpy-V, WOL-X, DWT, DT and static tension types were performed.

Mechanical characteristics of an A 302 B type of material are summarized in Fig.1, while in Fig.2 the same characteristics for an A 542 type of material are shown.

On the basis of experimental data and their analysis the following conclusions could be suggested:

1) Method of measurement of crack arrest temperature (CAT according to the criterion of shear lips of crack parabola or a temperature T_K according to the criterion of parabola top) for various values of accumulated energy (in the range of cca 10^1 to 10^6 kgm) applicable to pressure vessels was developed and mastered, including the method of static crack initiation from an artificial notch-like defects

by electric sparkling.

2) Shift in K_{IC}, CAT and T_K values as a result of accumulated energy was determined (see Fig. 4); at the same time tests on plane plates are representative for application to pressure vessels. Calculated and actual critical defect sizes (or critical stresses for these defects) are in a good agreement, likewise the relationship between fracture toughness and CAT values dependences.

3) At higher values of energy (pressurizing by mixture of water and air) also propagation of shear crack took place - this crack is also arrested; temperature of this shear crack arresting, T_P, is less dependent on accumulated energy than CAT. While failure in vessels pressurized by water can be regarded to be a leakage only, failures in vessels with water and air mixture represent the typical "barrelling" effect - see Fig.6.

4) Even for high values of accumulated energy a temperature, at which propagation either brittle nor shear crack could occur, was determined. This fact could be used for the safety criterion of pressure vessels with gas content.

5) CAT values for pressure vessels depend first of all on following factors : type of material, vessel thickness, accumulated energy.

Under the title of "Nuclear reactor pressure vessels safety from the point of view of brittle cracks" this program was partially sponsored by the I.A.E.A. in Vienna during years 1968 to 1972.

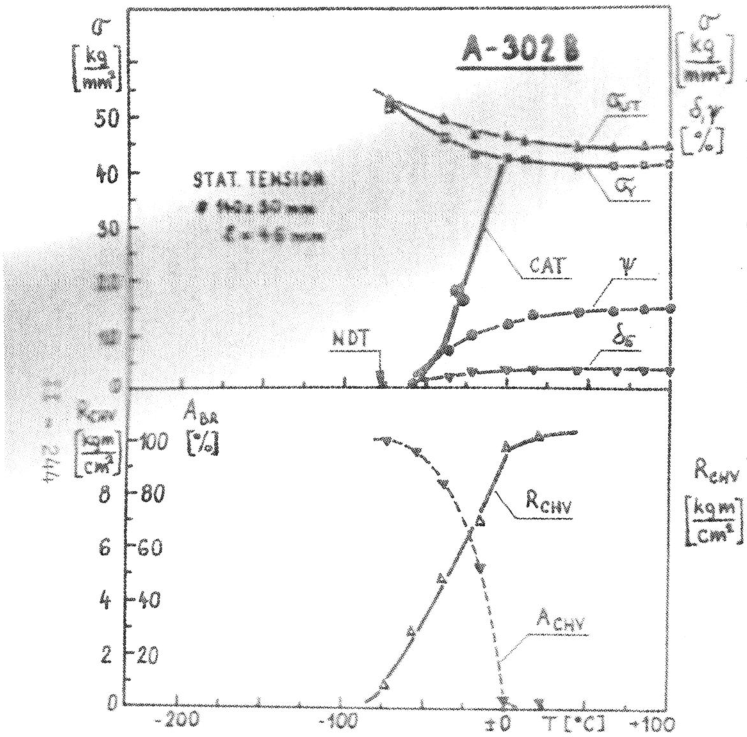

FIG. 1. MECHANICAL CHARACTERISTICS OF STEEL A-302 B, THICKNESS 30 MM

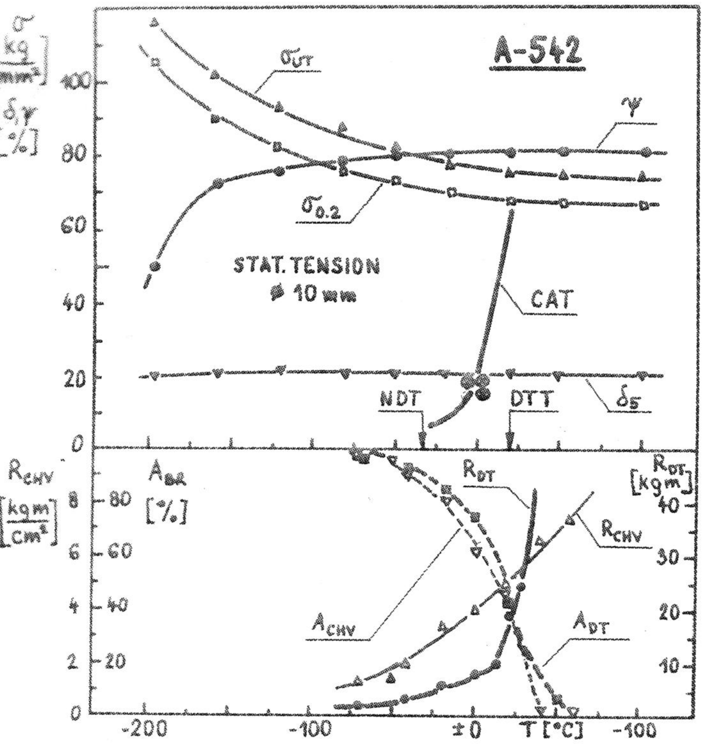

FIG. 2. MECHANICAL CHARACTERISTICS OF STEEL A-542, THICKNESS 30 MM

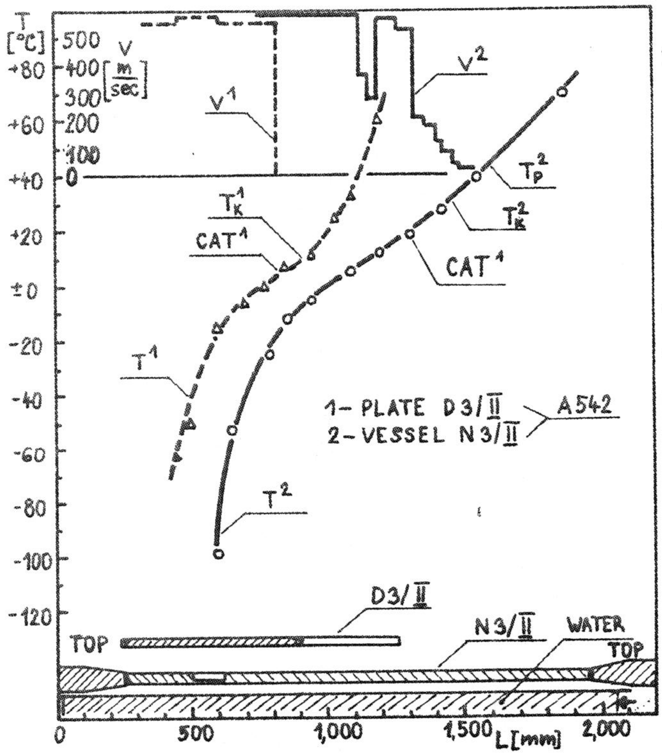

FIG. 3. TYPICAL TEMPERATURE GRADIENTS AND CRACK VELOCITY COURSES FOR 2ND SERIES OF TESTS

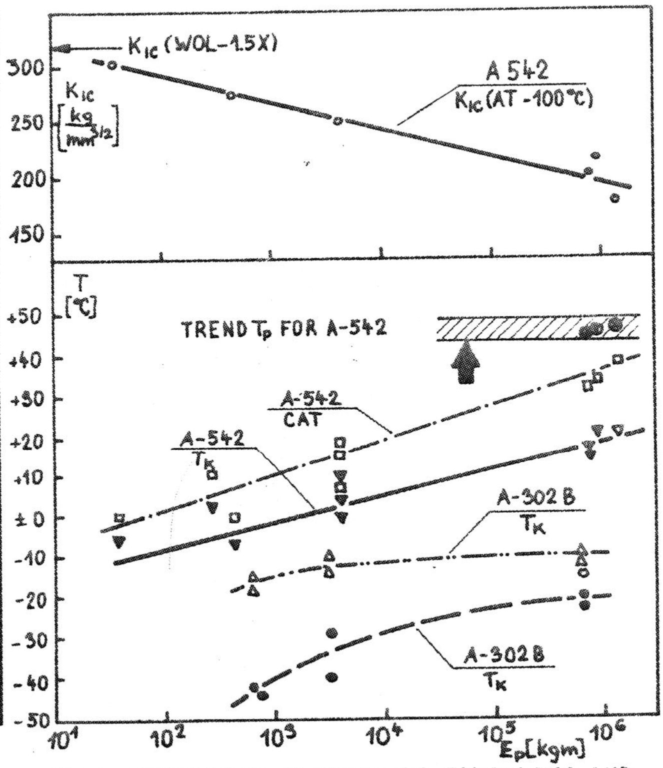

FIG. 4. DEPENDENCE OF FRACTURE TOUGHNESS AND CRACK ARREST TEMPERATURES ON ACCUMULATED ENERGY

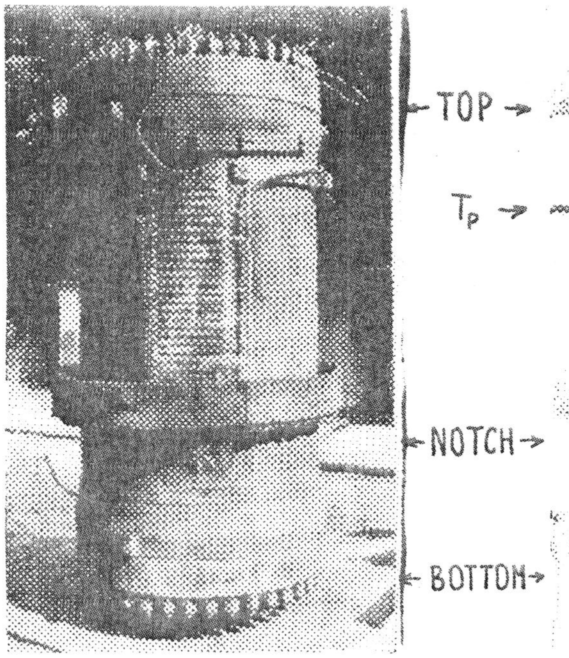

Fig.5. Photo of a vessel N3/II
(2nd series of testing)
before testing

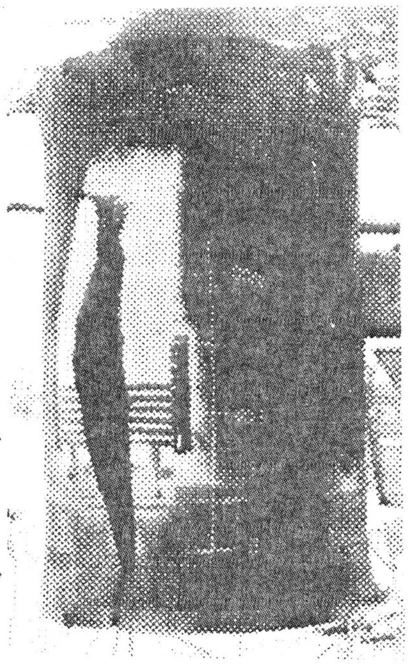

Fig.6. Photo of a vessel N3/II
(2nd series of testing)
after testing