

Dynamic Examination Technique for Large Specimens to Cover Incidents on Components with High Energy Rate

P. Julisch, H.-J. Hädrich, D. Sturm

*Universität Stuttgart, Staatliche Materialprüfungsanstalt (MPA),
Pfaffenwaldring 32, D-7000 Stuttgart 80, Germany*

Abstract

The influence of high loading rates on the stress and strain behaviour of large welded components cannot be estimated with sufficient accuracy from small scale specimens. The testing of welded plates using the actual wall thickness and realistic width is necessary. Consequently a high-speed tensile machine has been built at the MPA Stuttgart which uses gunpowder as a propellant to generate a maximum tensile force of 12 MN. The concept and the design of a model machine working on the same principle, were checked from numerous tests on austenitic and ferritic flat tensile specimens. Compared with the quasistatic tensile test, the results from the dynamic tested specimens showed that higher ultimate strengths and slightly larger deformations could be achieved.

1. Introduction

For nuclear power plants in the Federal Republic of Germany, for certain safety-relevant components, e. g. main coolant piping systems and some specific pressure vessels, it has to be proved that, in the cases of accidents with postulated high energy release rates and/or high dynamic loading conditions, integrity has to be guaranteed in the presence of flaws, **Fig. 1** /1, 2/. Thus, for instance, the system analysis for the Sodium Cooled Fast Breeder Reactor could show that an energy excursion of approx. 370 MJ has to be presumed. Other examples can be named from the field of light water reactors, e. g. the effect of an aircraft crash, and the reaction forces caused by waterhammer and earthquakes. These dynamic loading transients may lead to high strain rates in the safety-relevant parts. However, the design of safety-relevant components with statically or quasistatically determined material properties will not really cover the problems since inertia forces are not recorded and the constitutive laws and flow rules cannot be assumed to be equal. Since the weld seams are generally considered to be the safety-relevant areas of the structure, it is necessary to test specifically welded plates with as large as possible sections, this is usually done with wide plate-specimens.

The Federal Ministry for Research and Technology has funded the construction of a 12 MN-High Speed Tensile Testing Machine at MPA Stuttgart. This system is designed to be driven by propellant charge up to a maximum velocity of about 60 m/s. Additionally, an extensive test program is specified in order to determine the stress and strain behaviour of austenitic wide plate specimens at different strain rates.

2. Concepts of High Speed Tensile Testing Machines

Different concepts which differ mainly in the attainable velocity can be used for dynamic tensile tests, Fig. 2. While hydraulic and hydro-pneumatic testing machines cover the range of quasistatic tests up to a maximum velocity of approx. 12 m/s, high speed tensile testing machines driven by propellant charge attain approx. 60 m/s and rotary impact machines attain approx. 100 m/s. Concerning the hydro-pneumatic and rotary impact machines, the velocity is relatively constant during the impact test, whereas the high speed tensile testing machines driven by propellant charges attain the maximum velocity after a certain stroke, depending on the burning rate of the propellant and the masses to be accelerated. This peculiarity allows the loading history of the specimen to be controlled to be similar to the actual loading cases that could occur in the above mentioned components. Another advantage of a tensile machine driven by a propellant charge is that higher loads can be obtained from smaller testing equipment.

The operating mode of a high speed tensile testing machine driven by propellant is shown schematically in Fig. 3 together with an idealized energy scheme. Regarding its design, the machine corresponds to a conventional testing unit. However, all parts are adequately reinforced because of the high internal pressure, and acceleration dependent forces to be handled. The energy that becomes effective when the propellant is burnt separates into acceleration and deformation energy until fracture of the specimen occurs. Subsequent to the fracture, the remaining energy will be absorbed by deformation of a damping element.

2.1 1.2 MN-High Speed Tensile Testing Machine

A 1.2 MN-High Speed Propellant Driven Tensile Testing Machine was built as a model for the large similar system with a load capacity of 12 MN to keep within limits the constructive risk during the manufacture of the large machine, Fig. 4.

With this model testing facility several problems and phenomena were studied.

- With the aid of a ballistic calculation the velocity of the piston rod as well as the pressure history in the combustion chamber can be determined depending on the burning rate and quantity of the propellant charge as well as on the volume of the combustion chamber and the load/elongation behaviour of the specimen. It was shown that this theoretical model gave good agreement with the experimental results, Fig. 5.
- The kinetic energy stored in the accelerated parts, piston rod, gripend and specimen, of the planned 12 MN-High Speed Tensile Testing Machine be enormous. For this reason hydraulic dampers cannot be used. Best damping characteristics were found during the pre-tests with upsetting cylinders of Al 99.5 by which means high deformations and strain rates could be controlled in a safe way.
- The internal pressure of high speed tensile testing machines driven by propellant charge can rise up to 200 MPa in the combustion chamber. After several preliminary tests a hard-chromium multi-layer plating of 0.2 mm thickness seemed to be a suitable protec-

tion for the surfaces of the cylinder and the pistonrod. For the sealings U-cups could be used, shielded against the flame front by narrow gaps or piston rings.

For load measurements statical or quasistatical methods cannot be used in the high speed tensile testing machine. Best results were obtained using prestressed instrumented bolts which were integrated in the specimen head and calibrated separately. Depending on the width of the test plates, up to five bolts with strain gages coupled in Wheatstone bridges can be used, Fig. 6.

2.2 12 MN-High Speed Tensile Testing Machine

The 12 MN-High Speed Propellant Driven Tensile Testing Machine is being assembled and should be ready for service by mid 1985, Fig. 7 and 8. With this testing facility a velocity of approx. 25 m/s can be obtained after a stroke of 20 mm, and the maximum attainable velocity is approx. 60 m/s, Fig. 9. The machine components have to withstand high acceleration forces which exceed the pure tensile load by a factor of approximately 10. To attain these requirements the cylinder has been designed for an internal pressure up to 200 MPa using high strength steels. The total weight of the machine is about 400 tons. The machine will be suitable for testing, for example wide plate specimens, piping sections and fracture mechanics specimens, Fig. 10.

3. Testing Technique

The dynamic testing technique has, so far, been checked using high speed tensile tests on welded plates, made from either austenitic or ferritic materials. The dimensions of these specimens were similar but smaller than those of wide plate specimens. Most of them were welded with longitudinal and transverse weld seams and weakened by artificial flaws in the transverse weld seam to cover the most severe flaw states, Fig. 11. In all the tests on flat tensile specimens to date, material behaviour and load-carrying capability, under the checked conditions, vary in such a way that obviously higher ultimate strength values and elongations were measured on the dynamically tested specimens than were measured on the quasistatic tested specimens, Fig. 12 to 14. In the tests a stress criterion was then determined such that for a specified defect size in the net section of the specimens, the stress in the gross section equalled the yield stress. As a strain criterion remaining total strains of $> 1\%$ were aimed for, and were reached in each case by the test specimens related to a greater measuring length at flaw depths of up to about 20 % of the wall thickness.

4. Acknowledgement

The high speed tensile testing machines were funded by the Federal Ministry for Research and Technology, Bonn. The ballistic calculations for the machines driven by propellant charge were made by Rheinmetall AG, Düsseldorf. Carl Schenck AG in Darmstadt took charge of the construction of the 12 MN-High Speed Tensile Testing Machine, and the heavy parts were manufactured mainly by Krupp-Klöckner AG and Saarstahl GmbH.

5. Literature

- /1/ RSK-Leitlinien für Druckwasserreaktoren. Gesellschaft für Reaktorsicherheit (GRS) mbH, Köln, 3. Ausgabe, 14. Oktober 1981.
- /2/ DOERBECKER K., W. KELLNER and H. LAUBER: Analysis of Mechanical HCDA Consequences with the ARES Code for Demonstration of Primary Containment Integrity in SNR-300. 4th International Conference on Structural Mechanics in Reactor Technology, 15 to 19 August 1977, San Francisco, California, USA.

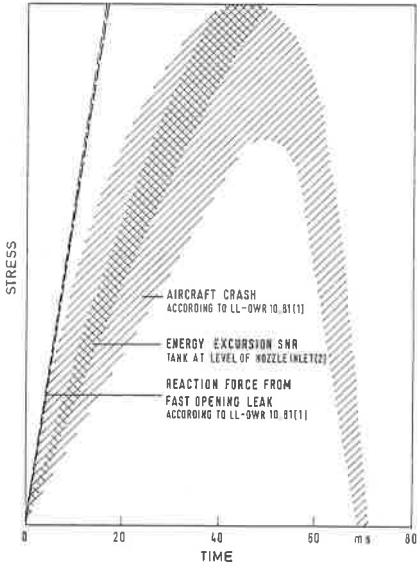


Fig. 1: Dynamic load transients for safety-relevant components of nuclear power plants

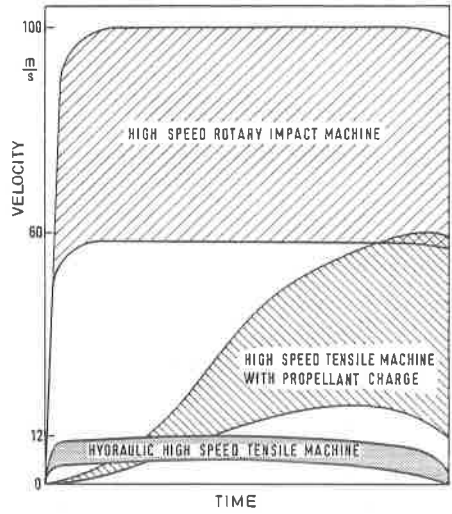


Fig. 2: Character of different testing equipment for tensile tests with high deformation velocities

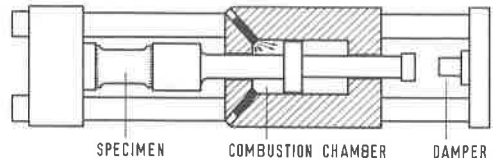
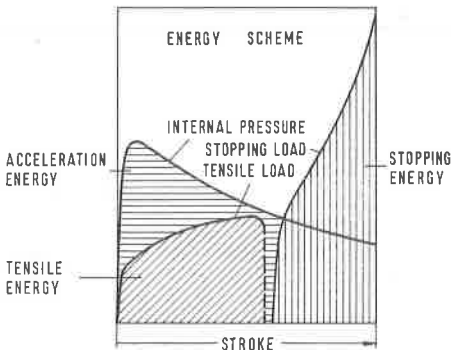
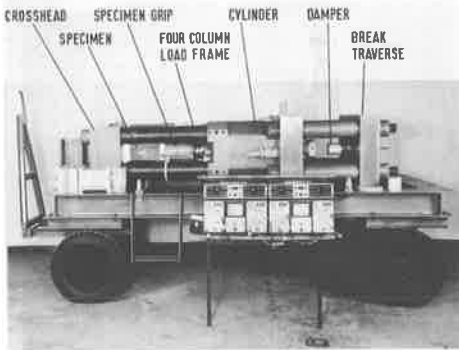


Fig. 3: Principle and energy scheme for High Speed Tensile Machines driven by propellant charge

1,2 MN-HIGH SPEED TENSILE MACHINE



LOAD	1,2 MN
STROKE	150 MM
VELOCITY AFTER 120 MM STROKE	40 M/s
LOAD FRAME STIFFNESS	10^{10} N/M
CROSS SECTION AREA	2 000 MM ²
MAX. INTERNAL PRESSURE	100 MPa
I, D. OF CYLINDER	250 MM

Fig. 4: 1.2 MN-High Speed Tensile Machine driven by propellant charge

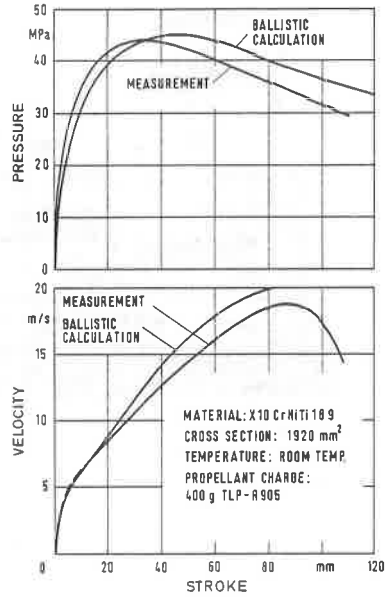


Fig. 5: Comparison of a ballistic calculation with measurement on a flat specimen made of X 10 CrNiTi 18 9 material

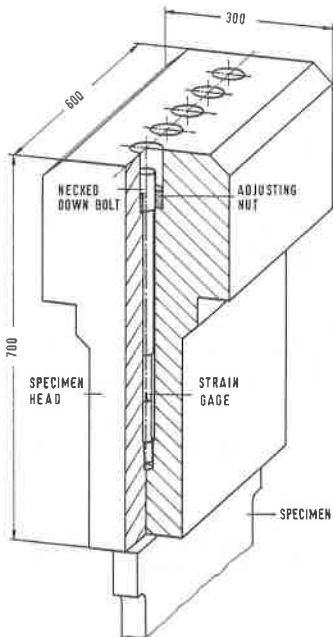


Fig. 6: Specimen head for 12 MN-High Speed Tensile Machine with transducer for force measurement

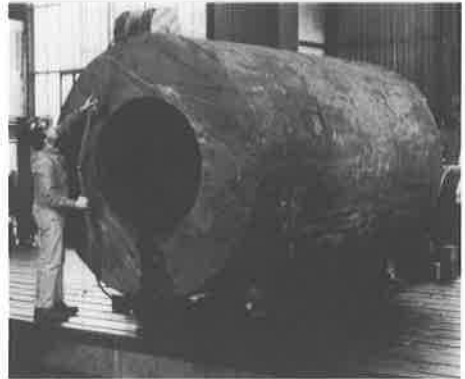
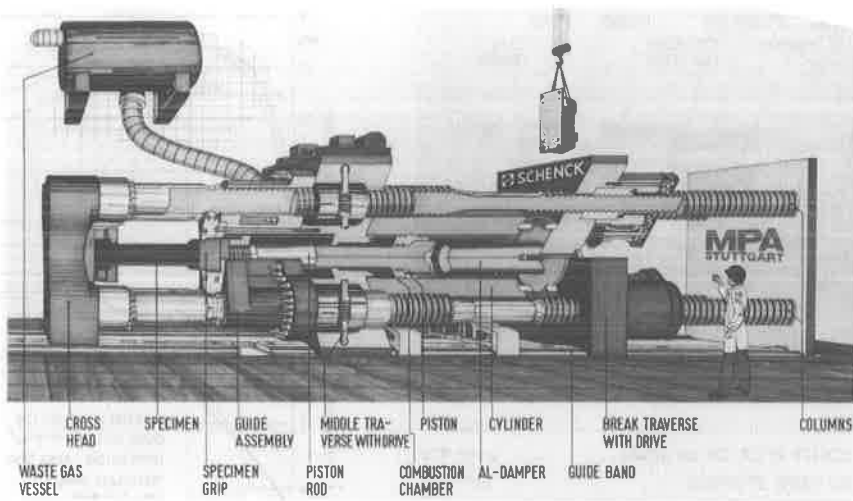


Fig. 7: Forged cylinder of the 12 MN-High Speed Tensile Machine



LOAD	12 MN	WEIGHT	TOTAL	400 T
ACCELERATING FORCE	100 MN	ACCELERATING PARTS		15 T
STROKE	400 (1300) MM	STRESSES	PISTON ROD	MAX. 900 MPa
LOAD FRAME STIFFNESS	10^{10} N/M		CYLINDER	MAX. 625 MPa
CROSS SECTION AREA	20 000 MM ²	VELOCITY	AFTER 20 MM STROKE	25 M/S
MAX. INTERNAL PRESSURE	200 MPa		AFTER 400 MM STROKE	60 M/S
I.D. OF CYLINDER	1 200 MM			

Fig. 8: 12 MN-High Speed Tensile Machine driven by propellant charge

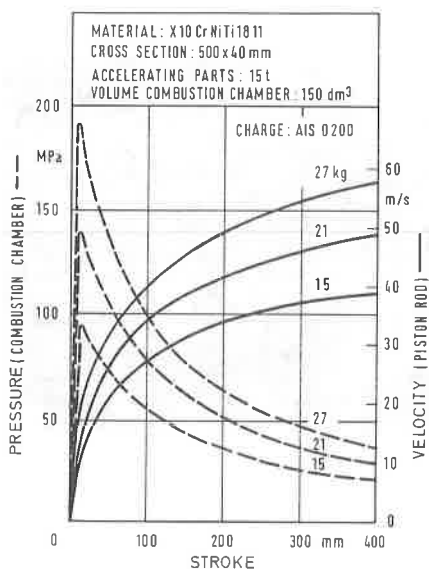


Fig. 9: Characteristics of the 12 MN-High Speed Tensile Machine shown for an austenitic wide-plate specimen

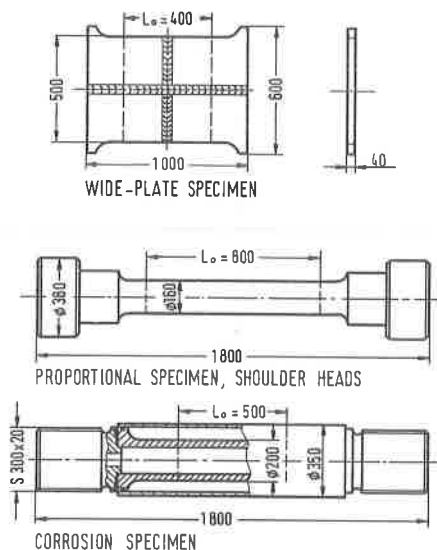


Fig. 10: Specimens for 12 MN-High Speed Tensile Machine

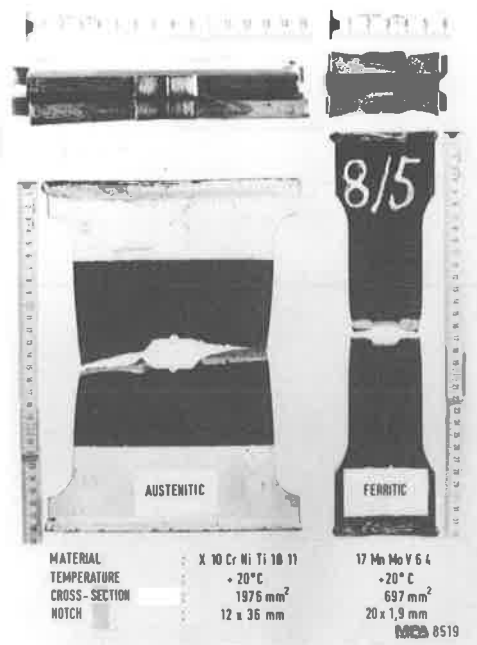


Fig. 11: Dynamically tested austenitic and ferritic flat tensile specimens

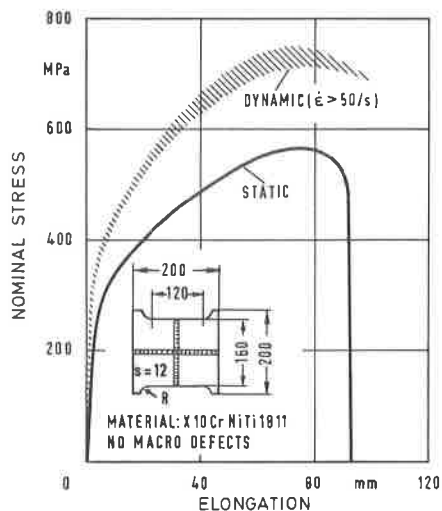


Fig. 12: Material behaviour of welded specimen tested quasistatically resp. dynamically

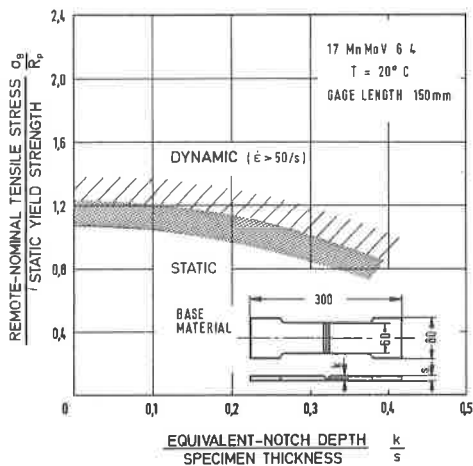


Fig. 13: Load-carrying capability of flat specimen tested quasistatically resp. dynamically

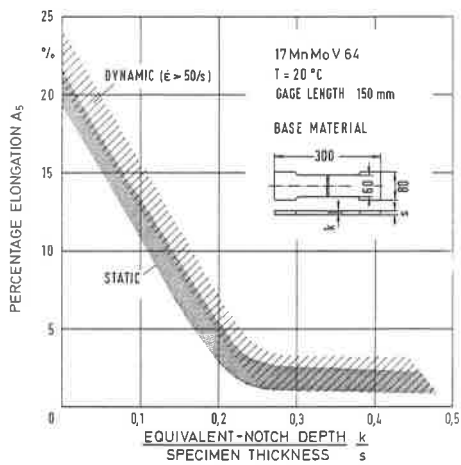


Fig. 14: Remaining strain of flat specimen tested quasistatically resp. dynamically