COMPARISON OF IMPACT TESTING ON CHARPY V-NOTCH SPECIMENS AND WOL-1X-SPECIMENS

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ABSTRACT

Commonly, instrumented impact tests are performed to measure fracture loads at high loading rates for determination of dynamic fracture toughness. It is well known that impact loading introduces dynamic effects which in some cases cause considerable error in determining fracture loads. Therefore, a critical review of instrumented impact testing is given in which these problems are discussed. Also, an alternative test technique is presented in which WOL-1X-specimens are loaded dynamically.In this technique, specimens are fastened to and moved with the load cell, in order to avoid acceleration effects and interaction between specimen and load cell during fracture process. Test series on three materials were performed and the results obtained by the two test techniques are discussed. The latter technique using WOL-specimens yields more reliable results.

KEYWORDS

Instrumented impact tests; fracture load; dynamic effects; impact loading on WOL-1X-specimens; dynamic fracture toughness.

INTRODUCTION

In the standard Charpy impact test, only the total energy absorbed in breaking a notched specimen is measured. In order to get more information on the material behavior under high loading rates, it is common practice to perform instrumented impact tests. The instrumented impact test provides load-time information in addition to the energy absorbed.
For better differentiation of the fracture behavior of materials, the dynamic fracture toughness parameter K_{Id} is determined. This requires a reliable determination of fracture loads. When an instrumented impact test is carried out at a hammer velocity of 5 m/s, the load-time curves as detected by strain gages placed on the tup or on the anvil display superimposed oscillations. These oscillations, the origin of which is entirely mechanical, make it difficult to interpret the results, especially the ones of those specimens that fail near the yield point. It can be demonstrated that the load signal measured on the tup or anvil does not correspond to the actual load on the specimen, especially when testing brittle

materials. Therefore, this paper gives a critical review of instrumented impact testing, and an alternative test technique is introduced in which WOL-1X-specimens are loaded dynamically.

INSTRUMENTED CHARPY IMPACT TEST

For this investigation, a 30 kgm impact testing machine was instrumented by cementing strain gages to the tup. The tup was welded to the striking portion of the hammer to prevent it from vibrating. The electrical signal was amplified directly and displayed on an oscilloscope. In order to avoid electrical damping, a frequency response of 500 kHz was provided.

Load-Time Trace

A typical load-time trace, as obtained by using this technique, is shown in Fig. 1.

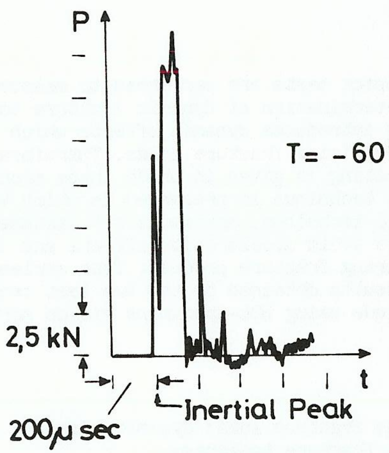

Fig. 1. Typical load-time trace of a Charpy V-notch specimen of 22 NiMoCr 37

During the initial loading of the tup, a discontinuity occurs before the load again increases. This discontinuity is known as the inertial peak, and with regard to its origin, it should be distinguished from subsequent oscillations. The inertial peak may be interpreted as the rigid body acceleration of the Charpy specimen. When the specimen is struck by the tup, it is accelerated rapidly from velocity zero to the velocity of the tup. In order to prove this physical interpretation, the following observations are brought forward in support:

1. The magnitude of the inertial loading is proportional to the hammer velocity or to the specimen's mass. Due to the difference in mass density, it has been shown that for aluminum-specimens the inertial peak is lower than for steel-specimens.

2. By comparing load-time traces obtained from instrumented tup and anvil, it has been shown that the inertial peak is recorded by the tup before the anvil registers its first load.

3. The inertial load exceeds fracture load when specimens are used which were already broken and cemented again before re-testing. These inertial loads are not observed when such a specimen is cemented onto the tup, (see Fig. 2) so that the velocities of hammer and specimen are equal at the moment of impact.

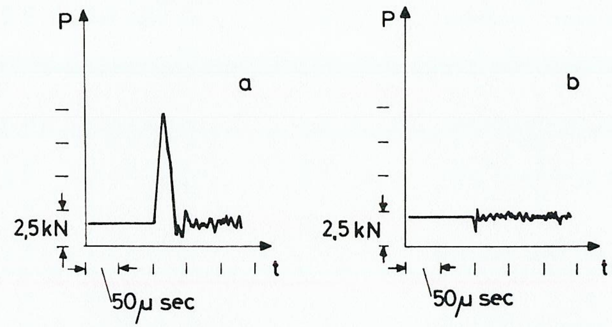

Fig. 2. Load-time traces of specimens consisting of two broken halves cemented together.
a. specimen resting on the anvil
b. specimen cemented to and moved with the tup

4. The magnitude of the inertial peak is nearly independent of the crack length of pre-cracked specimens, and in some cases may be even higher than the fracture load, as is shown in Fig. 3.

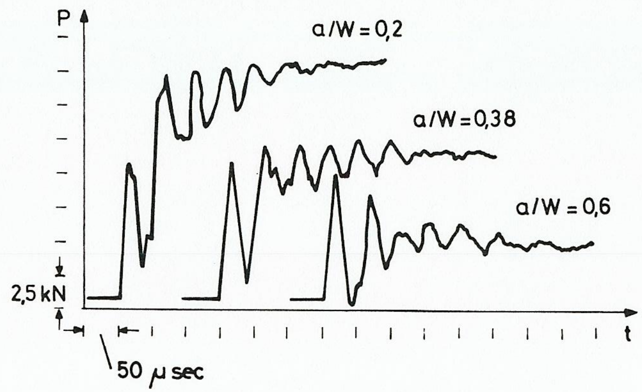

Fig. 3. Load-time traces of Charpy V-notch specimens of 22 NiMoCr 37 with various crack lengths a/W. Test temperature: 20 °C

By testing pre-cracked specimens cemented to the tup, however, no inertial peak can be observed, (see Fig. 4). In this case, the maximum load signal is dependent on crack length.
Subsequent to the inertial peak, further oscillations of the load signal are observed, which may be interpreted as a physical phenomenon caused by the interaction of anvil, tup and specimen, which are considered to represent individual spring-mass systems. As a consequence, tup and specimen are stimulated to vibrations of different natural frequencies by the impact, which interact in a complicated way during the fracture process.
By instrumenting the specimen with strain gages, it was shown that the load signal registered at the tup does not correspond to the actual load on the specimen. Figure 5 demonstrates that the load signal reaches its maximum value at the same time as the deformation signal reaches its minimum. This effect may be attributed to bending vibrations of the specimen during fracture process. Therefore, if the maximum load registered by the tup is assumed to be the fracture load, K_{Id} values calculated therefrom overestimate the true values.

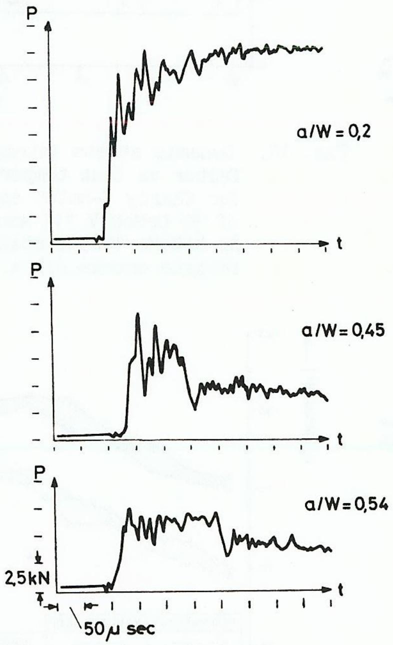

Fig. 4 Load-time traces of Charpy V-notch specimens of 22 NiMoCr 37 with various crack lengths. Specimens cemented to and moved with the tup. Test temperature: 20 °C.

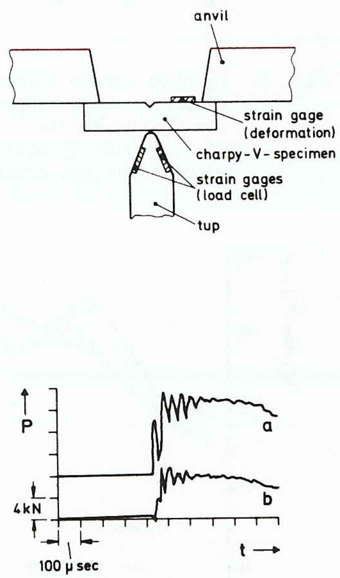

Fig. 5 Load-time signal (a) measured on tup, and strain-time signal (b) measured on instrumented Charpy V-notch specimen of 22 NiMoCr 37 at 20 °C.

Considering all observations described above, the following conclusions can be drawn. Error in measuring fracture loads results mainly for two reasons:

1. due to the effect of the inertial peak which is caused by the acceleration of the specimen's mass

2. due to oscillations of the spring-mass systems of tup and specimen during the fracture process.

Therefore, an alternative test technique as described in the following section has been developed in order to avoid such error.

INSTRUMENTED IMPACT TESTS USING WOL-1X-SPECIMENS

The experimental set-up which is shown schematically in Fig. 6 uses a standard impact machine. One end of a cylindrical load cell is bolted to the striking portion of the hammer. The specimen itself provided with a cross-pin is bolted to the other end of the load cell so that both form a rigidly joined common spring mass system. Measurements performed using this set-up do not show inertial peaks caused by acceleration of the specimen's mass, as the relative velocity between specimen and load cell is zero. (This can easily be proved by testing a specimen which consists of two halves cemented together.)

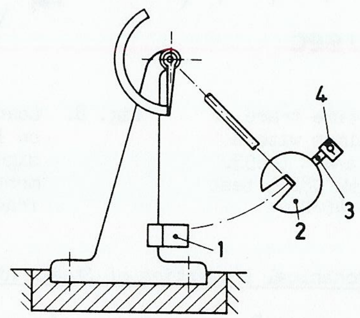

Fig. 6. Schematic of impact machine for testing WOL-1X-specimens (1 anvil, 2 hammer, 3 load cell with thread, 4 WOL-1X-specimen with cross-pin).

Figure 7 shows a typical load-time trace as obtained in such a test. Up to the breaking point, no oscillations are observed; however, subsequent oscillations cannot be avoided, as the load cell vibrates in longitudinal direction when it is unloaded abruptly at failure of the specimen.
By cementing onto the specimen strain gages registering its deformation, it can be shown that up to the breaking point the load cell and deformation signal correspond exactly. (see Fig. 8).

MATERIALS TESTED AND RESULTS

The mechanical properties of the three steels investigated are listed in Table 1.

Charpy V-notch specimens and WOL-1X-specimens, both containing fatigue cracks, were tested within the temperature range of -80 °C to 80 °C, using hammer velocities of 5,5 m/s. For the purpose of comparison, tests at slow loading rates were performed at room temperature. For determination of K-values, the maximum loads registered by the load cell were assumed to represent true fracture loads.

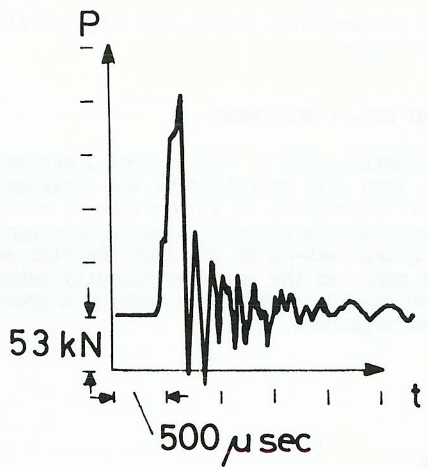

Fig. 7. Typical load-time trace of a WOL-1X-specimen with a crack length a/W = 0,653. Steel X2 NiCoMo 1885, test temperature: -40 °C.

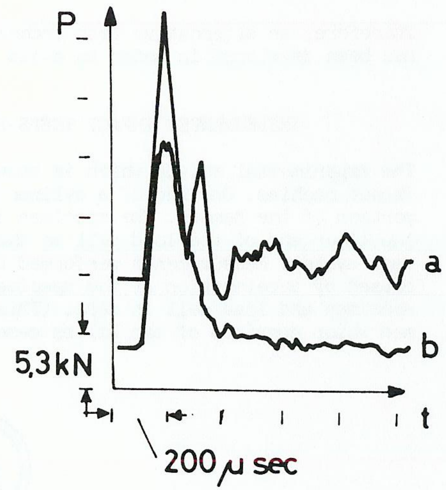

Fig. 8. Load-time signal (a) measured on load cell and strain-time-signal (b) measured on instrumented WOL-1X-specimen during fracture process.

TABLE 1 Mechanical Properties of Steels at 20 °C

steel	$R_{p0,2}$ Nmm^{-2}	R_m Nmm^{-2}	A %	Z %	A_v J
22 NiMoCr 37	517	657	31	71	180
30 CrMoNi V 411	636	782	5	6	13
X2 NiCoMo 1885	1810	1880	10	54	19

Figure 9 represents the results of steel 22 NiMoCr 37 using standard and pre-cracked Charpy V-notch specimens. Considerable scatter of K-values is observed at low temperatures in the range of brittle fracture.

In Fig. 10, the results of pre-cracked Charpy V-notch specimens of two relatively brittle steels are demonstrated. There is also considerable scatter of the data. No essential temperature dependence of K-values is observed.

In Figs. 11 and 12, the test results on WOL-1X-specimens containing fatigue cracks are represented. The K-values show relatively little scatter, exhibiting a temperature dependence, as expected. The K-values obtained from room temperature tests at slow loading rates do not exceed those obtained from impact loading. This is a rather unexpected effect and more investigation is necessary in order to clear this point.

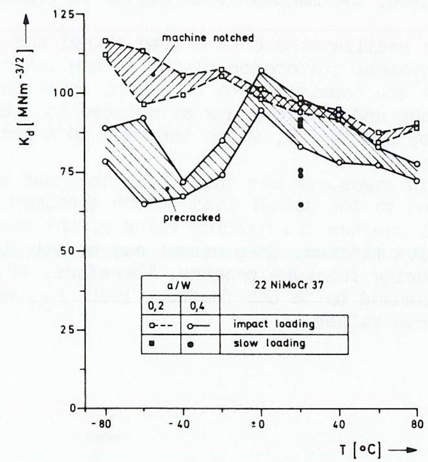

Fig. 9. Dynamic stress intensity factor vs test temperature for Charpy V-notch specimens of 22 NiMoCr 37 with and without fatigue cracks.

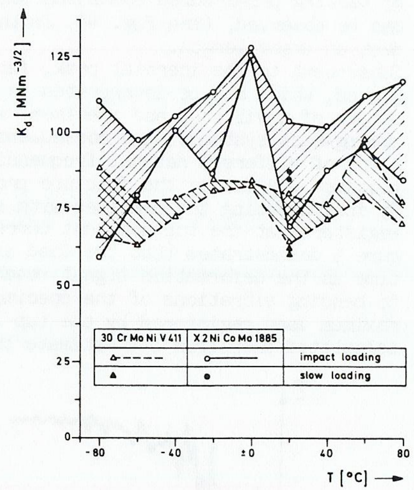

Fig. 10. Dynamic stress intensity factor vs test temperature for Charpy V-notch specimens of 30 CrMoNiV 411 and of X2 NiCoMo 1885 containing fatigue cracks a/W = 0,4

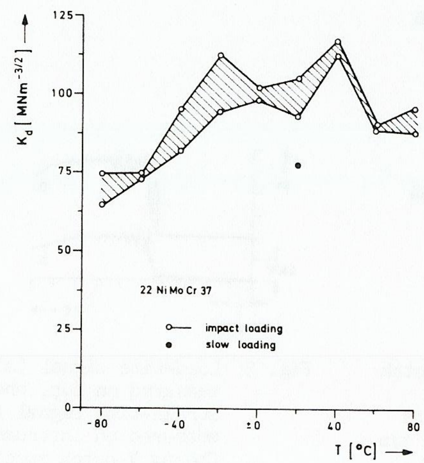

Fig. 11. Dynamic stress intensity factor vs test temperature for WOL-1X-specimens of 22 NiMoCr 37.

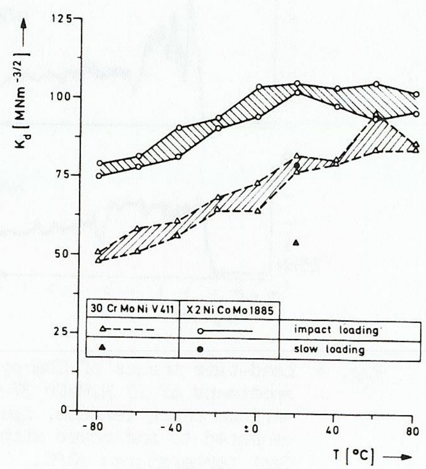

Fig. 12. Dynamic stress intensity factor vs test temperature for WOL-1X-specimens of 30 CrMoNiV 4 11 and of X2 NiCoMo 1885.

However, on comparing the two dynamic test methods, it can be stated that the differences arise from dynamic interaction between specimen and load cell during fracture process. From the test results, especially in the range of brittle fracture, it can be concluded that measurement of fracture loads is more reliable by using the test technique utilizing WOL-1X-specimens.

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