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METHOD OF DYNAMIC FRACTURE TOUGHNESS DETERMINATION OF CAST STEEL ON THE BASE OF THE CHARPY IMPACT ENERGY TEST

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Investigations of dynamic toughness and Charpy impact energy have been made for cast steel in the temperature interval from 20°C to −60°C. The experimental relationships between the critical value of J integral under dynamic loading conditions and the Charpy impact energy for different notch geometries and impact velocities have been determined. Mathematical relations between the measured values have been used to estimate the dynamic toughness of cast steel.

1. Introduction

During last years a number of failures of rolling stock components made of the cast steel and operating in siberian conditions was noticed. These accidents suggested the necessity of method to estimate the changes in dynamic fracture toughness with the decrease in temperature, which would be adapted to industry laboratory conditions. This paper concerns a testing technique in which the dynamic fracture toughness of cast steel is estimated on the base of Charpy tests results.

The instrumented impact Charpy pendulum designed in Foundry Research Institute makes it possible to determine the fracture toughness parameters under dynamic loading conditions. These parameters enable us to estimate the dimension of a tolerable defect in structures loaded dynamically. Such estimation is not possible on the basis of Charpy impact energy only. However, the Charpy energy test is easy to perform in a short time and therefore its results are frequently used as a basic criterion of materials acceptance in industry. For this reason, the research of a relationship between Charpy impact energy and dynamic fracture toughness in a given temperature range seems to be advisable.

To get the above, the investigations of dynamic fracture toughness and Charpy impact test have been made within a selected temperature range. The experimental results have been described with the help of mathematical equations in temperature. Next, a relationship between both obtained formulas has been established. These results made possible the prediction of an approximate value of the dynamic fracture toughness on the basis of Charpy impact tests only. It should be noticed that Charpy energy may depend on the notch shape, and therefore samples with different notch shapes were used.

In the seventies some papers were published (cf Barsom and Rolfe, 1970; Sailors and Corten, 1971; Marandet and Sanz, 1976), where the relations between fracture toughness K_{Ic} and Charpy energy KCV were discussed. However, these formulas are of an empirical nature only without the physical background. This is because the results refered to two different physical criteria (loading and energy), obtained at different loading rates on the samples of different geometries have been compared.

In this paper a method of the dynamic fracture toughness and Charpy impact energy testing based on the energy related principles was proposed and in both tests the samples of the same dimensions and geometry were used. In Charpy impact test several notch geometries and two loading rates (the loading rate which is typical of the dynamic fracture tests and the loading rate typical of the standard impact tests) were applied. In the dynamic fracture tests two notch geometries were used.

2. Material

The chemical composition of the tested cast steel is as follows (% by weight): C: 0.25, Si: 0.47, Mn: 1.38, P: 0.025, S: 0.020. The cast steel was normalized at a temperature of 890°C for 4 hours, and next annealed at a temperature of 600°C for 2 hours.

This grade of cast steel is frequently used for rolling stocks elements making.

3. Charpy impact tests

The tests were made utilizing a 150 J energy capacity Charpy pendulum. The tests at room and low temperatures were made on the samples of dimensions $10 \times 10 \times 55$ mm with different notch shapes. The samples with U-shape, V-shape and Y-shape notches were used. The Y-shape notch samples were remade from the U-notch samples by fatigue precracking. The Y-shape notch samples were used in the fracture toughness tests too.

The impact Charpy tests were made at temperatures of 20, 0, −20, −30, −40, −50, and −60°C. The fatigue precracked samples were loaded at two loading velocities equal to 2 m/sec and 5 m/sec, respectively. The velocity of 2 m/sec is recommended in impact toughness tests while the velocity of 5 m/sec is applied in Charpy tests.

The Charpy impact energies KCU, KCV and KCY versus temperature are shown in Fig.1. The denotation KCY_2 concerns Charpy impact energy for samples with Y-shape notch loaded at 2 m/sec, while the denotation KCY_5 concerns this type of samples loaded at 5m/sec.

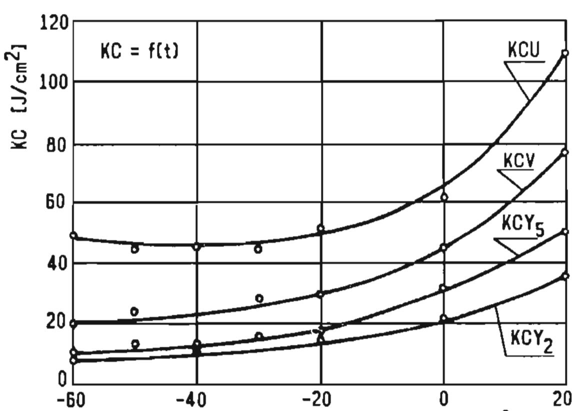

Fig. 1. Charpy impact energy versus temperature for samples with different notch geometry

4. Dynamic fracture tests

The fracture tests were made on samples of $10 \times 10 \times 55$ mm with two types of notch geometry. In most of the samples the V-shape notch was machined. In the other samples the U-shape notch was made. Both notches were 3 mm precracked. Fatigue precracking was made in agreement with the standard fracture test [6].

The dynamic fracture tests were made utilizing the instrumented impact Charpy pendulum. The details of the stand are given by Biel-Gołaska and Piekło (1991). The samples were tested at 20, 0, −20, −30, −40, −50 and −60°C, respectively. The samples were cooled in a bath of alcohol and CO_2. The fracture toughness was estimated using the J-integral criterion. The critical value of J was determined using multiple specimen technique developed in Foundry Research Institute (Biel-Gołaska and Piekło, 1991). The tested material revealed a significant plasticity and the application of a single specimen method, described in draft standard [5] was impossible. The critical values of J-integral versus temperature are shown in Fig.2.

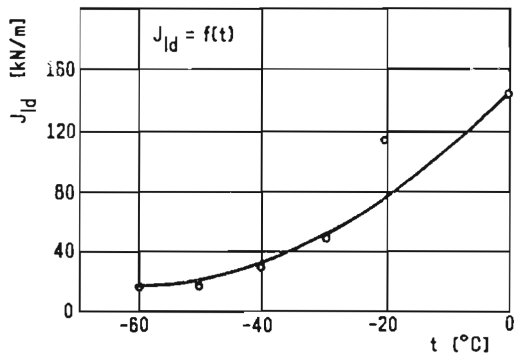

Fig. 2. Critical value of dynamic J-integral versus temperature

5. Discussion of results

The main aim of investigations was to set a mathematical (analytical) relationship between the results of dynamic fracture toughness and the results of impact energy tests within temperature range from 20 to −60°C. The dynamic fracture tests were made using the J-integral criterion at two impact velocities: 2 m/sec and 5 m/sec as usually is applied to Charpy impact tests.

The results of Charpy impact tests for three notch geometries and the results of dynamic fracture tests have been used to derive the equations in which the dependence of KCU, KCV, KCY_2, KCY_5 and J_{Id} on temperature are given.

The diagrams of Charpy impact tests and J-integral versus temperature for all the applied notch geometries have been described with the help of the same exponential equation

$$y = A \exp BT$$

These equations are as follows

$$KCU = 5.54e^{0.0093T} \; [\text{J/cm}^2] \tag{5.1}$$

$$KCV = 0.55e^{0.0164T} \; [\text{J/cm}^2] \tag{5.2}$$

$$KCY_5 = 0.52e^{0.015T} \; [\text{J/cm}^2] \tag{5.3}$$

$$KCY_2 = 0.30e^{0.017T} \; [\text{J/cm}^2] \tag{5.4}$$

$$J_{Id} = 3.67 \cdot 10^{-3} e^{0.0384T} \; [\text{kN/m}] \tag{5.5}$$

where T is temperature in Kelvin degrees.

By dividing Eq (5.5) by Eqs (5.1) $\div$ (5.4), the relation between J_{Id} and KC is obtained. For example

$$J_{Id} = 0.007e^{0.02T} KCV \; [\text{kN/m}] \tag{5.6}$$

$$J_{1d} = 0.012e^{0.02T} KCY_2 \; [\text{kN/m}] \tag{5.7}$$

Thus on the basis of Charpy impact tests results, the approximate values of critical J-integral J_{Id} can be calculated.

As it can be seen, the results of impact Charpy energy test decrease significantly with the notch sharpening. The Charpy energy values for U-notch shape samples are by $40 \div 50$ % higher than the values for V-shape notch samples, while the energy for precracked V-shape samples is by $40 \div 50$ % lower in comparison with the Charpy energy values for V-shape notch samples.

It is interesting to note that the increase in impact velocity from 2 to 5 m/sec does not change significantly the impact energy. It should be added that in spite of different notch geometries the shapes of Charpy impact energy versus temperature diagrams are similar. That means that the diagrams plotted in function of temperature are almost parallel to each other. This is confirmed by the similar values of coefficient B in Eqs (5.2), (5.3) and (5.4).

An interesting phenomenon, which confirm the earlier results obtained for other graders of cast steel, was indicated, that lowering of temperature does not always cause a decrease in toughness. The tested material exhibits the highest toughness at 0°C and not at 20°C, as it might be expected.

6. Conclusions

- The critical value of the dynamic J-integral J_{Id} can be determined on the basis of the results of impact Charpy tests for all the examined notch geometries and two loading rates utilizing the empirical equations.
- The sharpening of notch makes the Charpy impact energy values decrease. As a result,the energy for U-notch samples is by 40 to 50 % higher than the energy for V-notch samples. This energy is by $40 \div 50$ % higher than the energy for precracked V-notch samples.
- The investigations of into the precracked V-samples show that the loading velocity increasing from 2 to 5 m/sec has no essential influence on the Charpy impact test results.
- The results of Charpy impact tests performed on samples with different notch geometries have proved that the changes in energy with temperature are similar.

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Metoda wyznaczania dynamicznej odporności na pękanie staliwa na podstawie wyników prób udarności

Streszczenie

Badania dynamicznej odporności na pękanie oraz udarności staliwa przeprowadzono w przedziale temperatur od +20 do −60 [°C]. Ustalono empiryczne związki pomiędzy krytycznymi wartościami calki J przy obciążeniu dynamicznym i udarnością, wyznaczonymi przy różnych geometriach karbu i prędkościach obciążania. Dzięki wyznaczeniu powyższych zależności określono dynamiczną odporność na pękanie staliwa na podstawie wyników prób udarności.

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