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The Method for Determining Fracture Toughness and Impact Strength of 40АГФТ Steel

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Abstract

The article deals with the method for determining fracture toughness and impact strength of 40АГФТ steel. For the fracture toughness test approximate method of calculating energy characteristic (J_{IC}) was selected. After calculating energy characteristic, power characteristic (K_{Ic}) of fracture toughness was determined. Fracture diagram was recorded on the C8-2 electronic oscillator during testing. Strain meters were used to register the force. It is noteworthy that for determining structural strength of steels, specific work of crack propagation must be calculated by impact tests and recording the fracture process. For the testing, three 5mm x 10 mm x 55 mm V-notch 45^o sharp (r=0.25mm) standard prismatic specimens were used and arithmetic mean value was calculated. The tests were carried out on MK-30 pendulum impact testing machine.

Keywords: Steel, Round Billet, Fracture Toughness, Impact Strength, Strain, Bending, Cyclic Load, Microstructure.

Introduction

As it is known, the most reliable results for assessment fracture toughness of materials are obtained when testing specimens with preliminary initiated fatigue crack being the most common and dangerous defect of the structures (Gulyaev, 1986). The crack begins to propagate when the tension intensity coefficient or its expansion (during cyclic loads) exceeds a certain threshold and it involves three stages: increase in propagation speed; stable and relatively slow propagation; accelerated propagation ending with fracture. Fracture kinetics is described in diagrams recorded in the coordinates "crack length - number of cycles or cyclic loading time"; “crack length-static load time". Fracture kinetic parameters allow predicting durability of material in the construction (Kopaleishvili, Abdushelishvili, Kvirikadze, Kotiashvili, Kashakashvili, 2013).

Fracture toughness may be increased by: selecting optimal chemical composition of material; rational microalloying considering complex influence of the alloying elements; formation of optimal microstructures; reducing the amount of impurities, especially of easily fusible ones, segregated on the grain boundaries; choosing optimal modes of thermomechanical treatment after which the most desirable microstructure and parameters are formed; generating the surface layer, the structure and strains of which hinder crack nucleation (e.g. fine grain structure, compressive stresses, etc.).

If the mechanisms and machine parts are to work under impact load, the steel intended for their production must undergo static and dynamic tests. It happens that high strength steels fracture even under small impact load (Kotiashvili, 2008).

The results of dynamic tests greatly depend even on the slightest structural change of steels. Hence, the slightest or random changes in chemical composition or technology of steels, unnoticed during static tests, strongly affect the dynamic characteristics of steel properties (Kopaleishvili, Kotiashvili, Kashakashvili, Kopaleishvili, Makharadze, Chavchanidze, 2008). The goal of the present study is determining fracture toughness and impact strength of 40АГФТ steel.

Working Methodology

For fatigue testing, the 7x14x130mm specimens with 5 mm sharp notch were selected. The investigated surface of the test specimens was polished to the nearest 7th-9th grade and the approximate length of fatigue crack was predetermined. Each specimen was placed on Drozdovsky Vibrator and the crack was nucleated in it. During crack nucleation, variable load frequency was 5-10 Hz. Amplitude of oscillation was selected so that the crack nucleation time took

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1.5-2 hours for each specimen. For defining the JIC for each condition 5-8 specimens are required. In our case, 5 specimens were chosen for testing hot-rolled steel and 6 specimens – for testing hot-rolled and normalized steel.

After crack nucleation, the test was carried out according to the above scheme. The bending diagram was recorded in the coordinates "load-shift". Traversing speed was 3 mm/min. 1-ton mode was selected for bending. Each test specimen was loaded with different magnitude to obtain cracks of different length. Each load corresponds to its diagram.

Bent specimens were heated up to 400-450^{0}C temperature during 15 minutes for blurring the edges of the propagated crack and revealing its increment. After that the specimens were destroyed without recording a diagram.

On a broken specimen clearly are visible: 1) fatigue zone; 2) crack propagation zone (tinted or blurred areas); 3) The final breakdown zone of the specimen (undarkened areas). Photographs of broken specimens were made. Crack length (ℓ, mm), including the notch, was measured on the photographs. Area of crack increment was also measured and the obtained values were divided by the width of the specimen. Crack increment was calculated by this method: S/t = Δℓ, mm.

Following data were obtained on the bending diagram: 1) fT - maximum deflection (mm); 2) P_T - maximum load (N); 3) the work needed for bending the specimen (N · mm) can be represented by the formula:

$$\int_0^{f_T} P df_T = \frac{40 S_T}{20} = 2 S_T,$$

Where: ST is the diagram area enclosed by the load diagram and x-axis; it was measured with polar planimeter; diagram scales on the ordinate and absciss are 40 mm and 20 mm, respectively.

The specimens for impact tests were made from the stripes cut off the tubes. Cross-notch specimens were prepared on the milling cutter. For testing the specimens, pendulum was raised at the hight corresponding to 300 J potential energy. Fracture diagram was recorded on the C8-2 electronic oscillator during testing. Strain meters were used to register the force.

Polar planimeter ПР-2 was used for measuring the area corresponding to the work for crack propagation and the specific work of crack propagation KCV was calculated.

Results

High values of fracture toughness of 40AΓΦT steel, as well as high values of other characteristics of physic-mechanical properties, have been obtained after various heat treatment of hot-rolled steel, e.g. hot rolling + normalization at 9000^{0}C, hot rolling + normalization at 9000^{0}C + tempering at 6000^{0}C.

For hot rolled material, $y=147{,}29e^{0{,}3345x}$ and $R^2=0{,}8918$. For hot rolled + normalized material $y=107{,}96e^{0{,}3688x}$ and $R^2=0{,}9857$. In these equations x is the crack increment, and y –is J_I -integral, R^2 is the approximation of confidence value.

With the selected equations, for the zero increment of the crack (i.e. when x = 0) J_{IC} values of y were calculated. After examination, it was established that the J_{IC} values meet the requirements and therefore, they represent the fracture toughness of 40AΓΦT steel in hot-rolled condition as well as in hot rolled + normalized condition. For hot-rolled round billet steel J_{IC}=147n/mm and for the hot rolled + normalized material J_{IC}=108n/mm. The results of impact tests are given in Table 1.

Table 1. *Impact strength values of 40 AΓΦT steel after different heat treatment*

Type of treatment	Impact strength, KCV J / cm²
Round billet (before rolling)	56
Hot-rolled	73
Hot-rolledand normalized at 900°C	110
Hot-rolledand tempered at 600°C	123
Hot-rolled, normalized at 900°C and tempered at 600°C	142

Conclusion

To sum up, fracture toughness test results of 40AΓΦT steel indicate that after controlled rolling the metal is hardened, being proved by the high value of J_{IC}. On the one hand, high values of J_{IC} were conditioned by hardening effects of Vanadium, Titanium and Nitrogen additives and dispersed carbides, nitrides and carbonates formed on their base and on the other hand, by the plastic deformation effects during controlled rolling.

The data obtained after studying fracture toughness of 40AΓΦT steel prove that in hot-rolled condition strength and plasticity characteristics are of an optimum combination. Value of structural strength of the steel is promoted not only by some of the features of physico-mechanical properties but also by the whole complex of these characteristics including the high fracture toughness value.

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