FATIGUE PROPERTIES OF ADI CAST IRON

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Abstract

Austempered ductile cast iron is part of a family of heat-treated cast irons. Isothermal hardening transforms ductile cast iron into ausferritic cast iron (ADI), which has the appropriate characteristics of strength, the impact strength and fatigue resistance. ADI is more resistant per unit weight than aluminium and so resistant to wear as steel. The values of tensile strength and yield point are twice as high as values of the standard cast iron. The article presents the results of fatigue tests of the ADI cast iron with the use of load high frequency in the area of ultra-high cycle.

Keywords: ADI, Ultra-high-cycle fatigue, S-N curve

1. INTRUDUCTION

Austempered ductile iron is part of a family of heat-treated cast irons. Isothermal hardening transforms ductile cast iron into ausferritic cast iron (ADI), which has the appropriate characteristics of strength, impact resistance and fatigue resistance. ADI is more resistant per unit of weight than aluminium and so resistant to wear as steel. The values of tensile strength and yield strength are twice as high as values of the standard cast iron. Fatigue strength is just 50 % higher, and can be increased accordingly by shot peening or fillet rolling. ADI cast iron is a material which, moreover, like other grades of ductile cast iron, is incomparably superior in heat conduction and vibration damping from cast steel. Interesting history of applications of ADI is observed starting from the beginnings of its existence, when in 1976 General Motors Company in Detroit (USA) announced that this cast iron will replace carburized forged steel previously used for gear wheels of conical screw gear unit to the rear axle of Pontiac cars. Further applications are mainly replacing carburized steel, until the time of publication in International Harvester research demonstrating the superiority of crankshafts from ADI from heat treated steel forgings. The same company has attempted to perform from ADI cast iron track links for tanks. Still other applications include diesel engines for trucks and tractors and engines with turbocharging, turbine engines and engines for racing cars. Prototypes of connecting rods and other vehicles elements such as shock: absorbers, drive shaft yoke, short shafts, steering system components, slidable rollers of gear change and universal joints are examples of currently investigated prototypes. In the literature [1] you can meet a lot of examples of applications of ADI cast iron on structures used in various industry branches and technology. There are dominating relatively small products, which are most often exploited under the conditions of high and dynamic loads, in many instances they are subject to strong friction. "Which material will offer the constructor the best combination of low manufacturing costs, designing flexibility, good workability, high ratio of strength-to-weight and good ductility, resistance to wear and fatigue? Perhaps the ADI is the answer to this question. "- So begins the extensive work available on the Internet and concerning many details of ADI cast iron production [2].

2. FATIGUE PROPERTIES

Fatigue strength is the ability of material to resist fatigue process. Attempts of metal fatigue rely on repeated burdening the sample, causing alternating stress state. The variability of stress at the time τ is characterized by a frequency f, the size and type of stress and asymmetry coefficient of R cycle. Increased fatigue strength of material is gaining importance in solving the general problem of improving the reliability and durability of modern machines and structures. Analysis of causes of failures of machine elements and structures indicates that the majority of more than 90 % of all cases is due to fatigue cracking. Many factors have an effect on the fatigue properties. Belongs to them, anticorrosive protection in the form of the coating and also applied technologies of laser processing and electrolytic machining [3÷8]. At the actual operation, the components and constructions are loaded mainly by repeating loading that could lead to the ultimate state, fatigue fracture in the final consequences. If it is assumed that the construction material will be repeatedly cyclically loaded in the operation, then it will be necessary to determine very complex fatigue characteristics for the given operation conditions. It means to state experimentally the concrete values from the area of the low-cyclic, high-cyclic and ultra-high-cyclic fatigue for the construction material and by respecting of the philosophy of the admissible defects, also the values of fracture mechanics. To determine the fatigue characteristics mentioned above experimentally, there is usually realized the determination using the normal frequencies, in the range from $f \approx 10$ Hz to $f \approx 200$ Hz, that is very time demanding and expensive. This statement emphasizes the fact, that fatigue fractures occur even after billion cycles and more [9] and the stated, conventional criteria [10] do not fulfil the requirements for the safety and evaluation of components and constructions endurance. Sakai, T. et all [11], Masuda, C. et all [12], Naito, T. et all [13], Bathias, G. and Bonis, J. [14], Asami, K. and Hironaga, M. [15] stated f. e. the decreasing of the fatigue characteristics, dependence $S_a = f(N)$ beyond conventional limit of cycles $N_f = 10^7$, first of in the high strength and surface hardened steels (for example Hardox steel). One of the possible directions is the application of experimental methods of high frequency cyclic loading to determination of the fatigue properties in construction materials. These experimental methods are progressive without question, with a wide future application, they are very time and economically effective [16, 17].

3. MATERIALS AND EXPERIMENTAL PROCEDURE

For fatigue tests were used samples made of ductile cast iron ADI. ADI cast iron was obtained by heat treatment of cast iron of ferrite-pearlite warp. The chemical composition, mechanical properties and isothermal transformation parameters are shown in **Table 1**.

Table 1 Chemical composition (in wt.%), heat-treatment and mechanical properties ADI

C [%]	Mn [%]	S i[%]	P [%]	S [%]	Rm [MPa]	Z [%]	KCU2 [J·cm^{-2}]
3.49	0.25	2.46	0.002	0.007	1124.6	9.75	20.4
Heat-treatment austenitization × isothermal transformation 1183 K, 30 min × 673 K, 60 min							

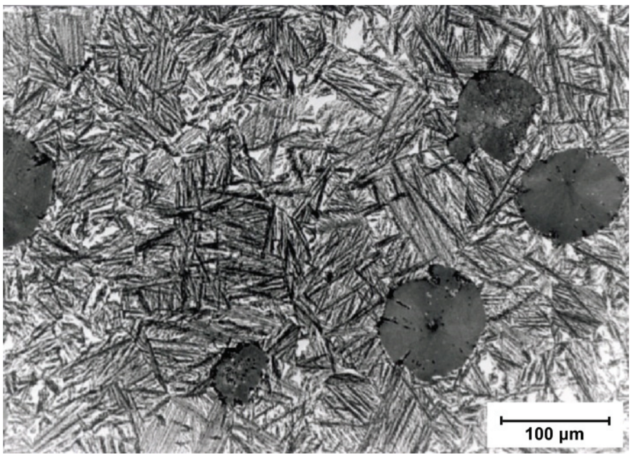

Fig. 1 ADI cast iron microstructure (bainite and retained austenite with nodular graphite), mag.400x

The microstructure of the material after isothermal transformation constitutes acicular ferrite (often referred to as bainite) and the residual austenite, regular graphite (VI 90 % according to STN 42 0461) and irregular graphite (V 10 %), the graphite particle size ranged from 15-30 μm. ADI cast iron microstructure is shown in **Fig. 1**.

In the research was used the resonant fatigue machine KAUP-ZU. Resonant method compared to non-resonant provides more stress amplitude and greater efficiency. Forced vibrations frequency in resonant conditions approaches the natural frequency of the machine-to-sample system. Samples on resonant machines are sensitive to changes in the stiffness of the sample at the time of the formation of fatigue cracks. Resonant fatigue machine is made of a piezoelectric transducer, tapered concentrator, gradual concentrator and test sample. **Fig. 2** shows the construction of the resonant fatigue machine. Resonant device allows you to produce in the smallest cross-sectional of the elastic-plastic sample deformation. In this place occurs accumulation of fatigue stresses leading to fatigue crack.

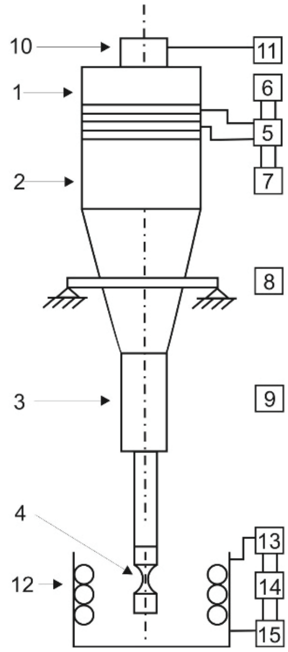

Fig. 2 Design of the resonance fatigue testing machine KAUP-ZU

Fatigue tests of ADI cast iron in the area of very high load cycles ($N \approx 6 \times 10^6 \div N \approx 1 \times 10^{10}$ cycles) were performed at high frequency loads of stretching-compression type with sinusoidal course ($f \approx 20$kHz, $R = -1$, $T = 20 \pm 10$ °C with cooling the samples in distilled water with anticorrosive inhibitor) on the machine KAUP-ZU with the use of the samples described by Salama and Lamerand (**Fig. 3**) according to the methods described in [10, 18].

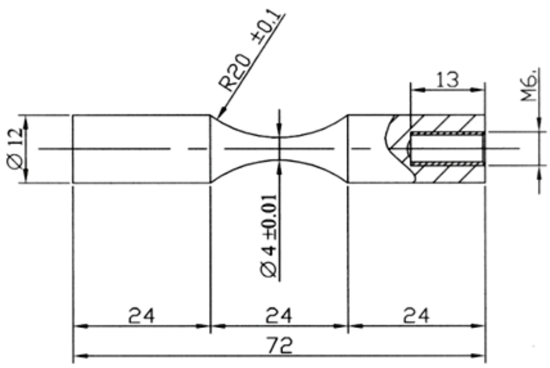

Fig. 3 Shape and geometry of the specimen used for fatigue tests at loading frequency of $f \approx 20$ kHz

4. SULTS AND DISCUSION

For $N_f = 4.3 \times 10^7$ cycles the amplitude value for the ADI cast iron is $\sigma_a = 190$ MPa with increasing number of cycles to $N_f = 1.10^{10}$ the amplitude value is $\sigma_a = 175$ MPa. (**Fig. 3** curve). Obtained amplitude difference in considered interval is $\Delta\sigma_a = 15$ MPa. Comparing obtained results with the results published in works [16] in which the authors investigated the fatigue properties of ductile iron (ADI R_m = 1250 MPa at load frequencies (f = 20 kHz, T = 20±10 °C, R = -1) in the area to N_f = 1 x 10^8 cycles (**Fig. 4**.curve) was obtained a similar course of dependence σ_a = f(N_f) placed in papers [10, 18, 19]. It should be stated here that it is based on a possible course of dependence σ_a=f(N_f), which requires more research. Comparison of the fatigue limit values σ_c at the low frequencies loading N_f = 1 x 10^7 cycles with fatigue limit σ_c with high frequencies loading N_f = 1 x 10^8 cycles, indicate higher values of σ_c with high frequencies loading cycles [1, 18]

Fig. 5 and **Fig. 6** show a breakthrough to the nature of ductile cast iron ADI after fatigue tests with the use of assumed load cycles (**Fig. 5**, N_f = 4.148 x 10^7cycles; **Fig. 6** N_f = 4.45 x 10^9 cycles). Fatigue fracture starts from the surface, for fatigue crack nucleation sites can be assumed primarily areas with graphite cast iron. Breakthrough of the ADI sample is characterized by trans-crystalline fatigue cracks. Surface relief at lower amplitudes of cyclic loading with a larger number of cycles to a breakthrough was lower.

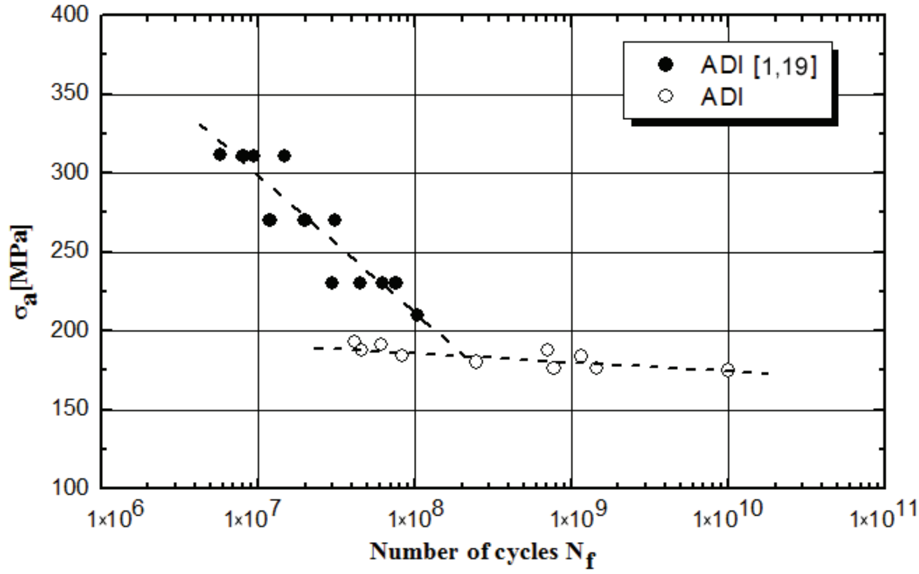

Fig. 4 The dependence of the voltage amplitude σa on the number of cycles N, cast iron and ADI [1, 19], (f = 20kHz, T = 20 ± 10 °C, R = -1)

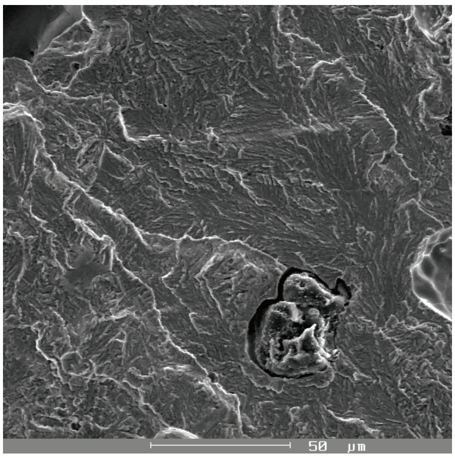

Fig. 5 The surface of fatigue fracture, cast iron ADI loaded N_f = 4.148 x10^7 cycles

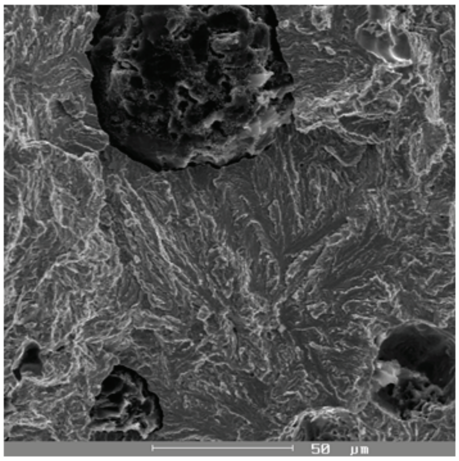

Fig. 6 The surface of fatigue fracture, cast iron ADI loaded N_f = 4.45 x 10^9 cycles

5. CONCLUSION

ADI cast irons are increasingly used for the relevant parts of machines exposed to dynamic load changes. It is advisable to know fatigue properties and cracking mechanism in the field of ultra-high cycle to determine the safe operation service life. The breakthrough of ADI sample is characterized by trans-crystalline fatigue cracks. Surface relief at lower amplitudes of cyclic loading with a larger number of cycles to a breakthrough was lower. Knowledge obtained during high frequency loading can be confronted with the works of the authors [19, 20], who analysed the characteristics of spheroidal cast iron loading to $N_f = 1x10^8$ cycles ($f \approx 20$ kHz $T = 20 \pm 10$ °C, $R = -1$) or with the work of authors [21, 22], who studied the fatigue characteristics of spheroidal cast iron to $N_f = 1x10^7$ cycles at low frequencies cyclic loading. For the above-mentioned ranges of cyclic loading were not observed significant differences between the low frequencies and high frequencies cycle loading. Subsurface fatigue crack initiation in the analysed region is a microstructure-related phenomenon which considerably affects the endurance of ADI. Subsurface fatigue crack initiation is associated with internal structural heterogeneities such as inclusions, micropores, microshrinkage, big graphite particles, long grain boundaries suitably oriented to loading direction, small grains, etc.

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