EFFECT OF PROCESSING FACTORS ON THE CRACK RESISTANCE OF STEEL VNS-2


High-strength martensitic stainless steel VNS-2 (EP410U, 08Kh15N5D2T), strengthened during aging to a level of 135±10 kgf/mm², is widely used in the fabrication of large and important power-plant elements. An important characteristic of the reliability of such elements is the critical stress intensity factor in plane strain $K_{IC}$.

The quantity $K_{IC}$ permits us to determine the critical length of crack leading to failure under service loads, evaluate the life of structures at a known rate of subcritical crack growth, compute safety factors, determine schedules for in-service inspections, etc. [1, 2].

The present work examines the effect of the structural and phase composition of steel VNS-2 on the type of fracture, value of $K_{IC}$, and the tendency toward delayed fracture. We also examined what optimal modes of heat treatment can be used industrially and what heat-treatment practices to avoid.

The value of $K_{IC}$ was measured on 50-mm-thick specimens in nonaxial tension. Specimen dimensions, method of fatigue crack application, and method of determining $K_{IC}$ conformed to standard requirements for determining fracture toughness in plane strain [3]. A study of corrosion cracking was conducted on fatigue-cracked specimens 13 mm thick subjected to non-axial tension. Specimens were loaded by means of calibrated disk springs in compact units installed in a corrosion chamber with the spraying of 3% NaCl solution. The effect of metal-lurgical hydrogen on delayed fracture was studied by loading similar specimens under atmospheric conditions on lever-type machine IP-2, providing a constant load. The value of the effective stress concentration factor was computed using well-known formulas for specimens in off-center tension [3].

The fractures were inspected visually at low magnifications and under an electron microscope by means of plastic-carbon replicas. The amount of austenite was calculated on the basis of the measured value of saturation magnetism $4\pi I_S$.

Optimum strengthening heat treatment of steel VNS-2 after hot plastic deformation consists of annealing at 650°C, quenching from 1000°C in water until darkening and subsequent cooling in air, and aging at 425°C for 2 h. Such heat treatment produces fine grains (7–9 points), with the structure consisting of acicular martensite with 10–15% residual austenite and no carbide networks along the boundaries of the original austenite grains. In this case the mechanical properties of the steel are as follows: strength $0_{U} \approx 130$ kgf/mm²; reduction-in-area $\psi \approx 60$%; Menage specimen impact toughness $a_n > 10$ kgf·m/cm² and, for fatigue-cracked specimens, $a_{f.c.} > 4$ kgf·m/cm²; $K_{IC} > 500$ kgf/mm²/². Plastic strain and large shear lips are seen in the fracture of failed specimens after the standard heat treatment (Fig. 1a). Electron microscope fractography showed substantial local plastic strain, with the fracture structure here being characterized by a fine- and coarse-dimpled relief (Fig. 1b).

Deviations from the optimum heat treatment mode may produce important changes in the structure of steel VNS-2 that raise the danger of premature, brittle fracture.

Slow cooling during the quenching of large parts leads to the precipitation of carbide networks along the boundaries of austenite grains within the temperature range 850–500°C. After aging at 425–450°C, the toughness of steel with the carbide network is sharply reduced

*Deceased.
†Measurements of $K_{IC}$ were made by L. A. Pastukhova.
Fig. 1. Macrostructure (a, c, e) and electron fractographs (b, d, f) of fracture surfaces of steel VNS-2 after different heat treatments: a, b) quenching from 1000°C, water cooling (air + aging at 425°C); c, d) quenching from 1000°C, cooling in sand + aging at 450°C; e, f) quenching from 1200°C + annealing at 650°C + quenching from 1000°C, cooling in water and air + subzero treatment (−70°C), 2 h + aging at 450°C.

($a_n \approx 3$ kgf·m/cm², $a_f, c \approx 1$ kgf·cm/cm², $K_{IC} \approx 210$ kgf/mm³/²). A decrease in $K_{IC}$ by a factor of two to three signifies the possibility of fractures at crack lengths 5-10 times less than in metal in the optimum structural state.