ON THE RELATIONSHIP BETWEEN MICROSCOPIC CLEAVAGE FRACTURE STRESS AND MICROSTRUCTURAL PARAMETERS IN A CAST HOT WORK TOOL STEEL

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Cleavage fracture of steels is generally accepted to be primarily stress controlled; according to this critical tensile stress criterion two conditions must be fulfilled at a sharp crack for a cleavage crack to propagate: i) the maximum local tensile σ_{yymax} must exceed the microscopic cleavage fracture stress σ_F^* of steel; ii) σ_F^* must be exceeded over a microstructurally determined "characteristic distance", ahead of the crack tip (1).

The microstructural features controlling resistance of steels to cleavage fracture have not always been identified with certainty. This is particularly the case of complex microstructures, like acicular bainite or tempered martensite; for such complex microstructures micromechanistic models of cleavage fracture are still in the development stage.

Identification of the principal microstructural feature is made difficult not only by microstructure complexity, but also by the statistical nature of cleavage fracture dependance on microstructural parameters; furthermore, more than one microstructural feature often appears to be in competition in controlling steel resistance to cleavage.

The microscopic cleavage fracture stress σ_F^* has proved to be of considerable use in investigations of cleavage fracture micromechanisms, since it is considered a material property, nearly independent of temperature, strain rate and test piece geometry.

Several physical models have been proposed to account for the microstructural mechanisms of local stress intensification and nucleation or propagation controlled cleavage fracture in simple microstructure steels. Some of them foresee a dependence of σ_F^* on $d^{-1/2}$ (2-3) (where d is the grain size), on $c^{-1/2}$ (4-5) (where c is the carbide thickness) or on $l^{-1/2}$ (6) (where l is the carbide interspace), while in other models (7-10) more complex relationships between σ_F^* and microstructural features take into account the influence of both grain size and carbide thickness.

The same models have been used to interpret cleavage fracture in complex microstructure steels, taking into account further microstructural parameters like bainite or martensite packet size, martensite lath width, austenite grain size, inclusion distribution.

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A further relationship between microscopic cleavage fracture stress σ_F^* and microstructural parameters can be obtained starting from the following equation, reported by Petch (10) to compute the critical carbide length, while deriving his non-equilibrium crack in the carbide model:

$$c = \{(2\gamma_p - nb\sigma/2\sqrt{2}) \pm [(2\gamma_p - nb\sigma/2\sqrt{2})^2 - n^2b^2\sigma^2/4]^{1/2}\}/[\pi(1-\nu)\sigma^2/2\mu] \,..(1)$$

where γ_p is the effective surface energy for the passage of a crack from carbide to ferrite, the product $nb\sigma$ is the dislocation pile up which wedge opens the carbide, and μ is the rigidity modulus.

Critical carbide size, c_c, for unstable spread of the crack can be obtained by putting the square root term in eq.1 equal to zero; solving for γ_p, substituting in eq.1 and recalling that, according to Petch, $nb = (1-\nu)k_y d^{1/2}/2\mu$, the following simple equation can be obtained:

$$\sigma_F^* = (k_y\, d^{1/2})/(2\pi\, c_c) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where k_y is the Petch constant, i.e. the slope of the grain size dependence of the yield strength.

Applicability of eq.2 has been assessed by means of recent results obtained by the authors for different heats of a cast H11 hot work tool steel. Detailed experimental procedures and results are reported elsewhere (11-12). Steel microstructures consist of lath martensite with spheroidized carbides precipitated during the third stage of sintering.

Table I summarizes experimental results. A yield strength dependence of martensite packet size can be remarked, with $k_y = 34.6$ MPamm$^{1/2}$.

Experimental σ_F^* values have been obtained (12) by means of the

TABLE I - Yield Strength, Cleavage Fracture Stress and Microstructural Characteristics of Steels

Steel	σ_Y (MN/m^2)	$\sigma^*_{F\text{exper.}}$ (MN/m^2)	$d_{\text{aust.}}$ (μm)	d_{pm} (μm)	c (μm)	$\sigma^*_{F\text{calcul.}}$ (MN/m^2)
1	1346	2787	20-80	7.2	.20	2342
2	1118	2455	>150	35.0	.64	1614
3	1294	2860	30	8.8	.18	2877

slip line field theory; no great differences with respect to σ_F^* values obtainable with more accurate finite element solutions are expected, since fractures occurred at loads well below the general yield loads.

If it is assumed that the microstructural unit controlling cleavage fracture is the martensitic packet, the σ_F^* calculated values in Table I can be obtained substituting d_{pm} for d in eq.2.

Calculated σ_F^* values do not show a large scatter with respect to experimental ones; the obtained results can be considered very encouraging, as a close agreement is obtained for steel 3 with a very homogeneous microstructure. A better agreement can be expected also for steels 1 and 2 if a statistical assessment of microstructure parameters is performed.

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