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Crack Patterns under Mechanical Loading

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Abstract

The fracture with the formation of crack patterns instead of a single main crack may occur in the structures for several reasons. The main factor is always the presence of high gradients through the depth of a structure at almost constant stresses near the surface. In this case a growing crack can get into the zone of low stresses and stop, and the fracture will continue by formation of new cracks. Such fracture type is typical for heat-stressed structures, but can also occur under mechanical loading. This paper discusses the possible mechanisms of the crack pattern formation. It is shown that in addition to the form of stress field, the fracture type depends on material properties - in particular, its creep. The considered fracture by crack pattern formation could be characteristic of not only the metallic structural elements, but also for the natural formations, for instance rock or ice massives.

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Keywords: Crack; crack pattern; thermal loading; mechanical loading; creep; steel; ice.

1. Introduction

Appearance of crack patterns in heat-stressed structures (metallurgical, power and chemical equipment) is well known for operators of such equipment – see for example [1-4]. Similar mechanism of crack pattern formation can be observer under other types of loading caused by non-uniform volumetric strains – like directional drying [5,6] or irradiation-induced swelling [7].

Mechanical loading leads to crack patterns formation much more rarely. The obvious reason is that in a structure subjected to given force appearance of crack usually increase stresses in the remaining intact cross-section an so accelerates crack growth – especially taking into account stress concentration near the crack tip (in contrast to the strain-controlled thermal loading, where release of strains due crack formation decrease stresses and can stop crack growth). Nevertheless in some cases crack patterns can appear under loading by given forces, some examples can be

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found in [8] – in particular, a pattern of radial cracks occurring near the fillets in the shafts of circular cross section under cyclic torsion: pattern which consists of cracks of different lengths: small and frequent, deeper but more rare. Some other examples are shown on fig. 1.

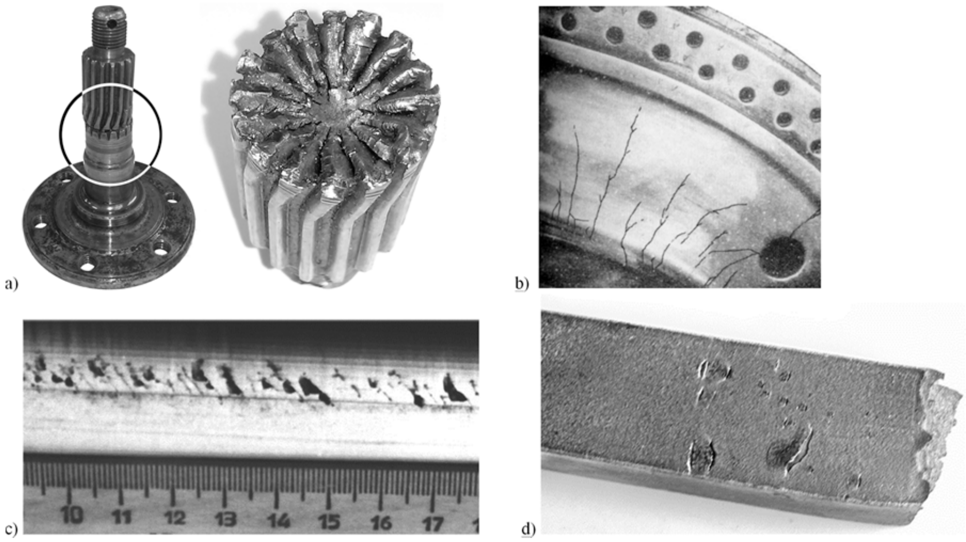

Fig. 1. Crack patterns appeared under mechanical loading: a) spline connections: system of axial cracks caused by cyclic torsion; b) cracks in steam turbine disk (Rezinskih V.F., Ginsburg E.S., Klypina A.M. etc., 1993); c) cracks in rails (surface layer of the rail is removed by machining); d) cracks on the surface of the stretched sample exposed to natural gas.

There are some possible reasons for formation of crack patterns rather than single crack. For example, in structures with number of sharp stress concentrators (like shown on fig. 1a,b) cyclic loading produce almost equal damages near the concentrators; the first appeared crack will grow while the crack tip leaves highly stressed (and highly damaged) zone, producing conditions for formation and growth of the second crack and so on. Another possible reason is moving loads which produce small enough but repositioning zone of high stresses – fig. 1c. Difference between properties of base material and surface layer of the structure can also provide crack pattern occurrence – fig. 1d. Some additional factors can contribute to stopping of growing crack and forming of another one – and finally of crack pattern: technological self-equilibrated stresses and their release due to cracks, changes in the stress cycle asymmetry and stress state (mean stress to stress intensity ratio) near crack tip, cyclic hardening and the heterogeneity of the material [8] including structural reinforcement – see, for example, [9]. This work concerns only two factors of all this diversity: moving load and the redistribution of stresses due to creep.

2. Moving load

One of typical fracture mechanism for bearings and gears is spalling (crumbling) initiated by fatigue crack pattern that forms at the structure surfaces. In most cases, such cracks are of sufficiently small size comparable to the material grains that make it impossible to apply classical approaches of fracture mechanics. However, there are some structures with large enough contact zones and cracks to apply such approaches. Typical examples are rails: monitoring carried out in South Urals branch of Russian Railways reveals cracks significantly surpassing material grain size – fig. 1c. The cracks appear in under-surface layer after sufficiently long operating time (about 10^8 wheel passages); distances between cracks are small enough to make it necessary consideration of adjacent cracks interference. As a first approximation, the fracture can be analyzed using mechanics of continua and its well-developed analytical or numerical methods.

Let's consider a problem of cylinder rolling on half-space. Let's suppose that some periodical cracks are already exists near the half-space surface and determine the kinetics of stress-strain state at crack tip – in order to determine