THE FRACTAL MODEL OF INTER-PORES CRACK GROWTH IN SINTERED STEELS

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Abstract The geometrical structure of sintered steel pores and their distribution is described in terms of fractals. The found correspondence between pore distribution and crack is examined. The fractal dimensions of crack generated from pores model (due to the simple proposed geometrical rule) and real fatigue crack are compared.

1. INTRODUCTION TO FRACTAL MODELS OF FATIGUE PROCESS

In the continual medium approximation we neglect short range scales compa-rable to distances between particles. On the other hand many important processes (like fatigue for example) take place or correspond to other range of length.

Under externai load applied to a sample all degrees of freedom at any scale range become excited. The input energy measured in terms of hysteresis loop flows down from macroscopic scale to deeper levels fig. 1.

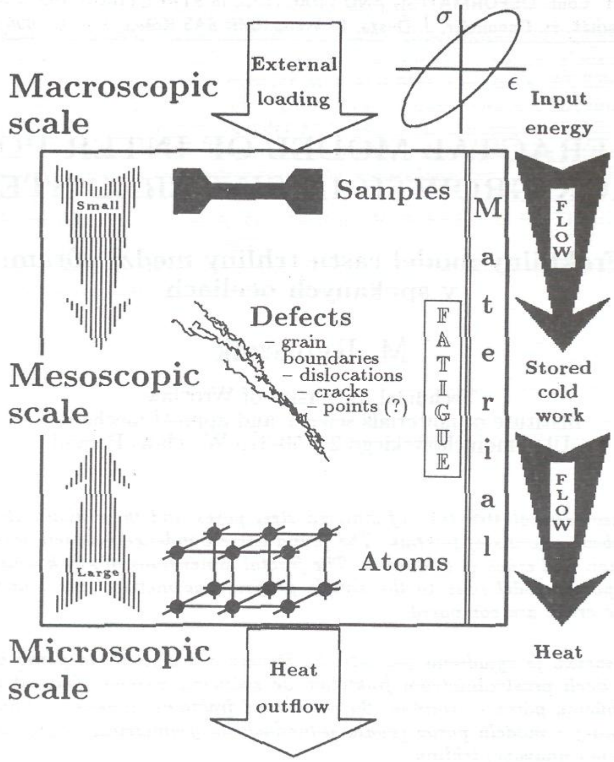

Fig.1 The energy accumulation in a material. The fatigue defect born at mesoscopic scale.

Finally at micro-level we obtain some heat outflow. As we know heat corresponds to oscillations of atoms.

Not all input energy flows out as a heat. Some part, called cold work, becomes stored at defects at mesoscopic scale. That entails the fatigue process related to an externai loading. The most important theoretical problem is to find the correspondence between macro- and meso-scopic picture of fatigue.

Defects at any stage of evolution are modeled by means of fractals with fixed fractal measure and dimension. Generally models of such type are constructed in two steps. At first we need state equation for fractal defects which links fractal variables.

The cold work ε stored at defect is assumed to be linear in fractal measure v_D but the proportionality factor $a(D)$ depends on fractal dimension D. Note that the fractal measure has been understood as and represented by suitable projective quantity. Next representing the projective quantity by suitable powers one obtains:

$$\varepsilon = a(D)\, v_D \qquad (1)$$

The mesoscopic length scale may also vary during defects evolution.

2. PORES IN SINTERED STEELS

The sintered steels are very brittle material with iniţial structure of pores in-volved by powder metallurgy. During fatigue process we observe the cracks growing between pores. The iniţial structure of defects evolves to final transparent crack in a sample. We have to model both: pore structure and fatigue crack.

According to applied range of magnification different elements of pore (and other defects) structures are put forward. The whole analysis is limited by discrete structure of a matter at atomic scale. Since we are interested in the correspondence bewteen structure of pores and final fatigue crack we begin with large magnification.

The example of pores are depicted in the Fig. 2. During fatigue process we observe the growing bridges between pores. In turn pores do not change in any noticeable way..

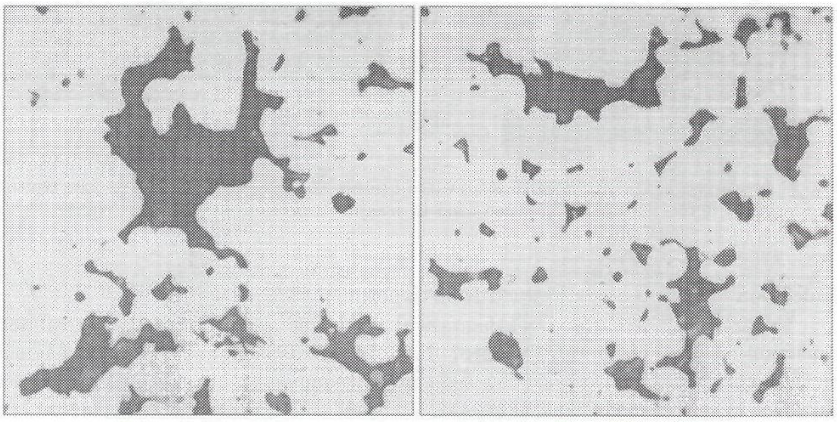

Fig.2 The two example of increase in pore

However there is not any visible connection beween structure of individual pores and growing transparent crack.
At first we look for the suitable range of magnifications. For each picture we estimate (box-counting) fractal dimension for observed structure of pores. Next computer finds contours of all pores and once more we evaluate fractal dimension for contours solely. We seek for range of magnifications in which the above two fractal dimensions coincide. An example is shown in the fig. 3.

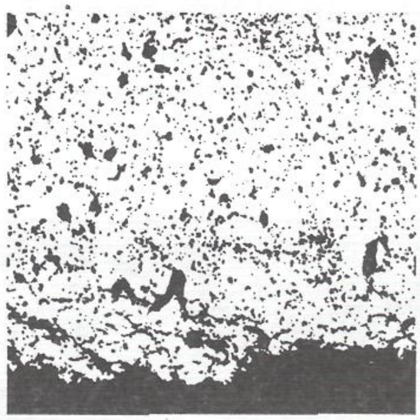

Fig. 3.a.
The observed pores and fatigue crak.

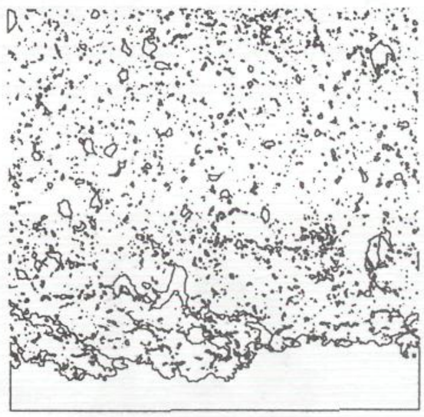

Fig. 3.b.
The pores and all defects used in fractal dimension estimation.

Then fractal dimension will depend on linear size of pores and their distribution solely but not on the internai structure of separate pores. Since details of individual pore form are not important we can model pores by points but the distribution of points should have the same fractal dimension as real structure.
Sintered steels are produced from powders and during technological process high pressures are applied. Therefore structure of grains, being dense packed, should be locally close to hexagonal one. In turn pores originate predominantly at surfaces of adjoint powder grains. In effect we expect the hexagonal structure to be visible also in spaţial distribution of pores. At large macroscopic scale the pore distribution becomes uniform and hexagonal order is missing. In effect the fractal modeling pore structure should be composed with hexagonal cells. Each cell contains a fractal with dimension close to value obtained from experimental observations.

3. CRACK GROWTH IN SINTERED STEELS

We generate a crack according to simple geometrical rule, which does not favorize any length scale. Suppose that we have two clouds of defects with a single common point. Then a crack should run through this common point and inside a cloud of defects we approximate crack by straight segment. Under current resolution we treat the cloud of defects as uniform defect. Increasing magnification we notice that iniţial cloud divides itself into smaller ones and we once more apply above crack form approximation. The procedure has been depicted in the fig. 4.

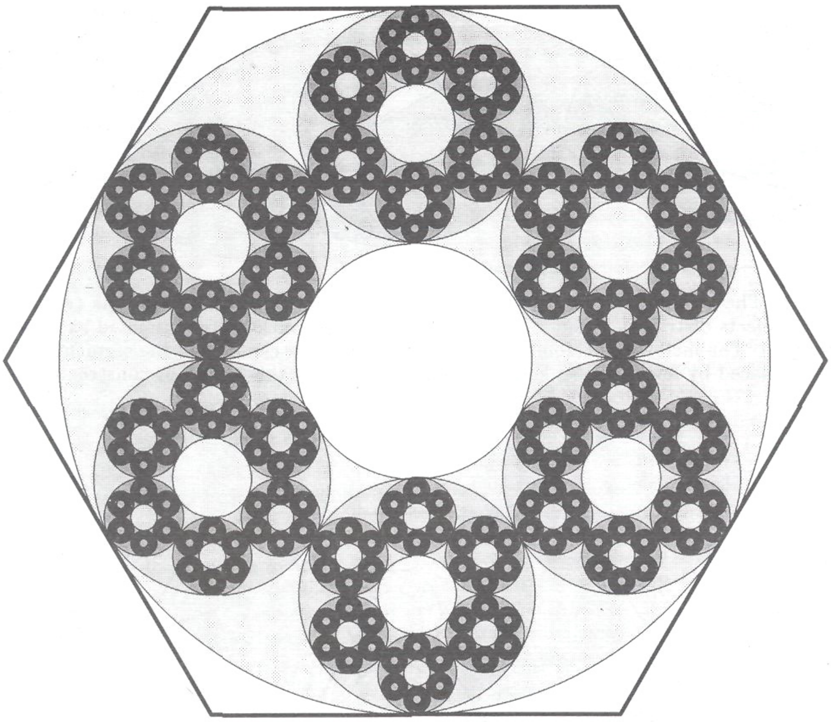

Fig.4. The intersection of the infinite secvence of defect structure inside.

The model crack (in fact formed from von Koch type curve shown in the Fig. 5) has fractal dimension In 5/In 3 = 1.47. At the same time fractal dimension of real crack equals 1.51. For both models: pore distribution and crack form, the model and experimental values of fractal dimensions nearly coincide. Model values are slightiy smaller because our construction doesn't employ any overîaping. Moreover the dusts filling cells are very regular.

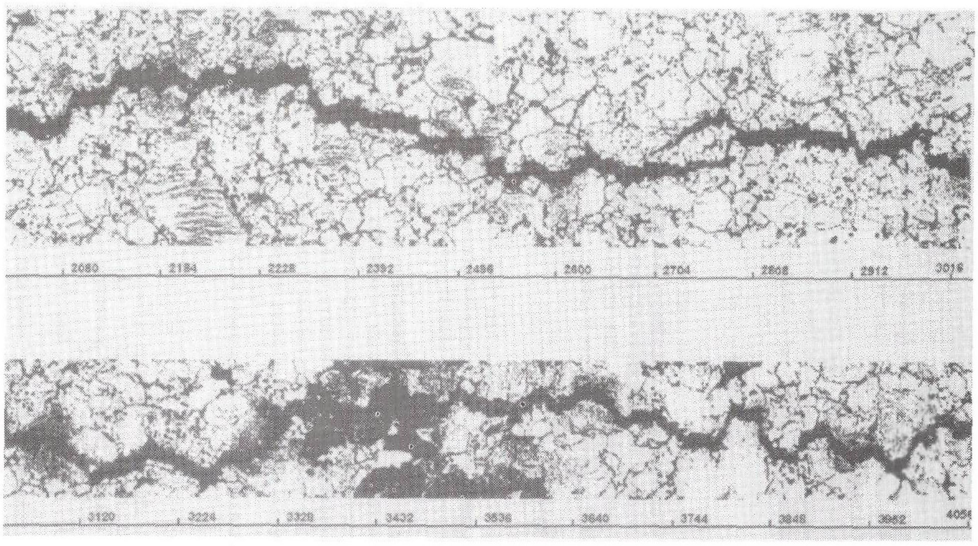

Fig.5. Fatigue crak inthe steel

To estimate the characteristic linear size of cells we evaluate numerically the relative partition entropy of fractal defined in the same way as in the ergodic theory, or in the theory of dynamical system.
To compare the fig. 5 presents the observed fatigue crack in sintered steel from the work . Some fragments of observed pattern have form quite close to the constructed fractal model.
The constructed models of pore distribution and cracks may be applied to study other important characteristics like stress intensity factor*,* the energy conserving cascade process examined in [3], [4].

4. CONCLUSION

The growing fatigue crack in sintered steel can be observed at many distinct length scales. At macroscopic level (large comparing to characteristic size of cell) the crack can be approximated by a smooth curve. No fractal character becomes visible.
At the opposite limit, at scale comparable to individual pores the crack contour is also quite close to smooth curve with relative low fractal dimension. Moreover there is no any correspondence between separate pores and fatigue crack form.
The crack form appears to be sensitive to the pore distribution solely. At the intermediate scale length when pores become points object there is close correspondence between fractal distribution of pores and fractal form of the final crack.

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