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THE FINE STRUCTURE IN DEFORMATION BANDS IN MILD STEEL

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ABSTRACT

The results are presented of the experimental investigation of the fine structure of deformation bands in mild steel which arise on deformation in conditions very close to the brittle state. It was found that there were two types of band. It is suggested that one type of band is formed as the result of a combination of twinning and kinking. These bands could be given the conventional name twinning layers.

The other kind of band is formed as the result of plastic deformation by bending and can be described as a bending band.

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In mild steel, under the action of impact and static loads at low temperatures, characteristic narrow bands are formed which are usually taken to be twins or twinning layers. This assertion is based on their orientation which in the majority of cases coincides with the crystallographic twinning systems in ferrite {121} ⟨111⟩ . The edges of these bands on the etched surface of a microspecimen may be straight or zigzag. They are observed both in polycrystalline and monocrystalline specimens /1/. In paper an attempt was made to explain the reason for the different shapes of the edges of these bands. In particular, the suggestion was made that the zigzag edge in twinning bands was the result of localized slip when the twinning layer reaches the surface.

It is known that besides twinning bands, deformation bands may be formed in ferrite /2,3/ or in other words, bending bands /4/. When studied under an optical microscope it will be found that the bending bands are very similar to traces of the twin layers /2/. Traces of these bands may erroneously be attributed to twinning layers. The attempt was made to obtain new data regarding the nature of their formation on the basis of a study of the fine structure of the bands which occur in mild steel after impact and static testing at low temperatures.

Investigations were carried out on annealed specimens of mild steel. Standard prismatic specimens were deformed by impact on the usual Charpy tester at temperatures 10-15° below critical embrittlement temperature. Cylindrical specimens 6 mm dia. with polished strips 2.0 mm wide exactly opposite to one another,were statically pulled at temperatures from - 170 to - 190°.

The surfaces to be examined were mechanically and electrolytically polished and then electrolytically etched /5/.

The results of the investigation have shown that after impact and static testing at temperatures close to the critical temperature for embrittlement, in ferrite grains two types of deformation bands are formed.

Under the usual kind of metallographic investigation these bands are very similar to one another and only very careful investigation makes it possible to distinguish them. After electrolytic polishing and etching, etching figures in the form of "Christmas-trees" will be formed on the first kind of deformation band trace. They consist of separate "drawn out" spots (etch pip). (Fig.1). It is interesting to note that this kind of etching figure on traces of deformation bands is not only characteristic for iron, it has already been observed on zinc twins /6/. They must therefore be characteristic of plastic deformation.

Startsev and Kosevich /8/ were able to show that twinning in zinc is accompanied by deformation of the crystal in the region adjacent to the twin which is several times greater than the twin itself. They came to the conclusion that, in this case, besides twinning there also takes place an independent form of plastic deformation by the kink formation,1/ which also creates in the twin a zone with a very distorted crystal lattice.

The results of the investigation carried out provide a basis for the suggestion that the first type of deformation band observed in polycrystals of α-iron is the result of a combination of two deformation mechanisms: twinning and kink formation.

Under the action of an applied load which creates shear stresses sufficient for the beginning of twinning, rapid growth

1/ Accomodation kink

of the twin takes places inside the grain (Fig.2a or the separate strokes - band 1, Fig.2b), and then fault formation develops along the twin. The comparatively high rate of deformation of the twin is predetermined by the dislocation mechanism /9/. The kink formation at the initial stage of development occurs by the emergence of a series of local micro-kinks along the twin (Fig.2a or the wide washed out band 2, Fig.2b). Under external load the number of micro-kinks is increased and, as a result of partial "overlapping", they merge with one another into a solid band which also absorbs even the twin (Figs. 3a, b).

The presence of traces of a much finer structure in the places where the band has formed than in the rest of the grain shows that the kinking is accompanied by very high immediate use of energy. The amount of energy expended directly in the process of twinning within the boundaries of one grain probably varies very little. In the process of kinking the excess energy not consumed in the formation of the twin itself is used up. The kinking process may therefore end at different stages (Fig.2 and 3) depending on the initial store of elastic energy and the amount used up in the growth of the twin. The intensity of the process of kinking, which depends on the load conditions and the properties of the metal, determines the shape and width of the band.

The problem of the correct classification of the first type of deformation band now arises. Should it be called a twinning layer or a kink band? Considering that the predominant process in the stage of nucleation of the band is probably, it might reasonably be termed a twinning layer. This includes the features of its structure on completion of the development stage.

The second kind of deformation band in polycrystalline α-iron can be seen under an optical microscope in the form of comparatively "uniform" bands with level or zigzag edges (Fig.4). Investigation of the fine structure under the electron microscope shows that these bands are a transition region between two parts of a grain which have been displaced to a certain extent (Figs.5a, b). The shap kink, and in some cases change of fine structure, is only observed at the boundary or in the boundary zones of this band. No noticeable change in the fine structure occurs inside the band. The only thing which changes is its orientation with regard to the fine structure of sections of the grain outside the band. The formation of this kind of deformation band seems to be related to the mechanism of plastic deformation by bending and consequently, it may be called a bending band.

In the early stages of formation of the band the amount of the bending at its boundaries is roughly similar. It is possible that bending bands along which there is a sharp change in orientation, are formed by the successive rotation of the crystal lattice as a result of the pile-up of a large number of one kind of dislocation in this plane /10/. As the deformation increases the intensity of bending on one of the boundaries may increase more rapidly than on the other. Non-uniform growth in the intensity of bending will cause excess growth of the line (plane) in the bending zone (Fig.6).

In later stages of development, slip will be observe in the bending zone and inside the bands (Fig.7). The development of slip to the formation of "steps" in the bending zone, from which the zigzag boundary of the deformation band will be formed (Fig.8).

The formation of the steps is promoted by slag inclusions. The black spots which are very often seen in the corners of steps on the boundary of bending bands after etching, are traces of the sharp distortion of the structure in this place. As the angles of these steps are stress concentrators, nuclei of cracks or slip bands will arise immediately around them (Fig.8b).

The tip of a developing band (Fig.9) is in the shape of a sharply pointed wedge. The high stress concentration which arises at the tip of a bending band causes considerable localization and rapid development of these bands. For the same reason the bending bands frequently intersect the boundaries between grains with slight disorientation very easily /11,12/, maintaining their shape and direction of development. Grain boundaries with considerable disorientation may hold up the development of the bands.

Where a developing bending band passes a grain boundary with considerable disorientation there will be considerable distortion and transverse dislocation of one part of the boundary with regard to the other in the direction of the development of the band. The nuclei of microcracks may arise in this case.

REFERENCES

1. D.Hull, Acta met., 8, 11 (1960).
2. C.S.Barrett, The structure of metals, Metallurgizdat (1948).
3. A.C.Cottrell, Dislocation and plastic flow in crystals (1958).
4. I.A.Oding, V.S.Ivanova, V.V.Burdukskii and V.N.Geminov, Teoriya polzuchesti i dlitel'n. prochn. metalloved. (The theory of creep and long-time strength of metals), Metallurgizdat (1959).

5. B.S.Kasatkin, Zavodsk. lab., 7, 842 (1958).
6. J.Gilman, J.Metals, 8, 8, 998 (1956).
7. B.S.Kasatking, Inzh.-fiz.zh., 1, 10, 106 (1958).
8. V.I.Startsev and V.M.Kosevich, Fiz. metal. metalloved., 2, 2, 320 (1956).
9. N.P.Allen, J. Iron and Steel Inst., 191, 1 (1959).
10. J.V.Hess and C.S.Barrett, J.Metals, 185, 599 (1949).
11. V.I.Arkhanov, Proc. Inst. Applied Mathematics, Urals Inst. of U.S.S.R. Academy of Sciences 16, 7 (1955).
12. B.S.Kasatkin and G.F.Darovskii, Fiz. metal. metalloved., 8, 6 (1959).

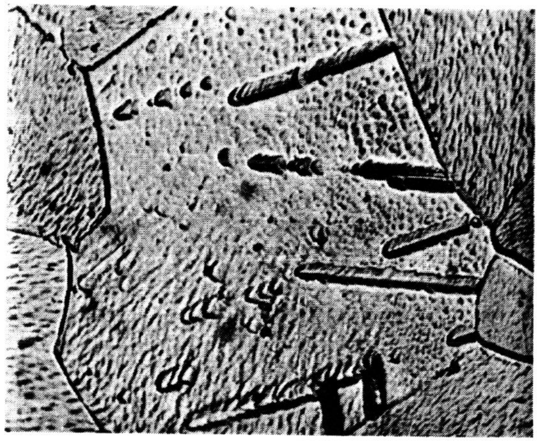
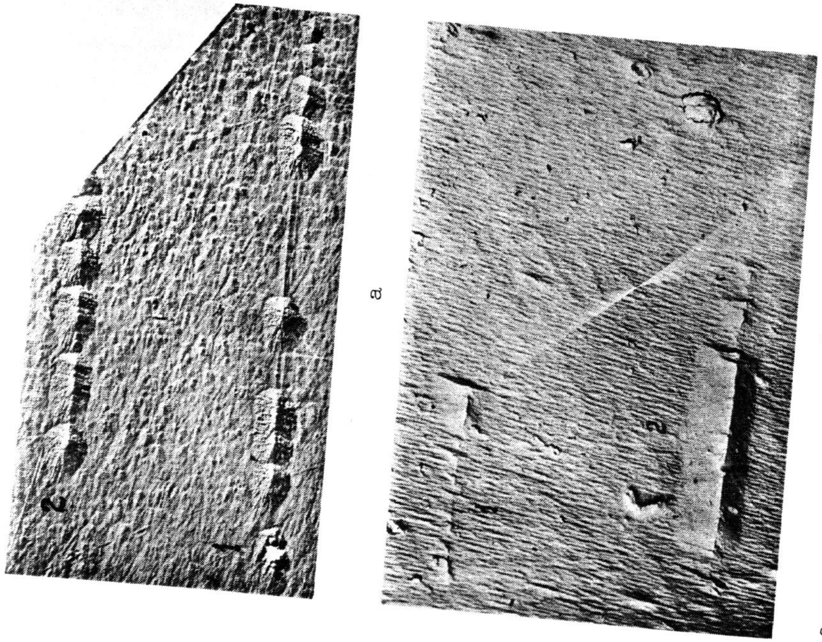


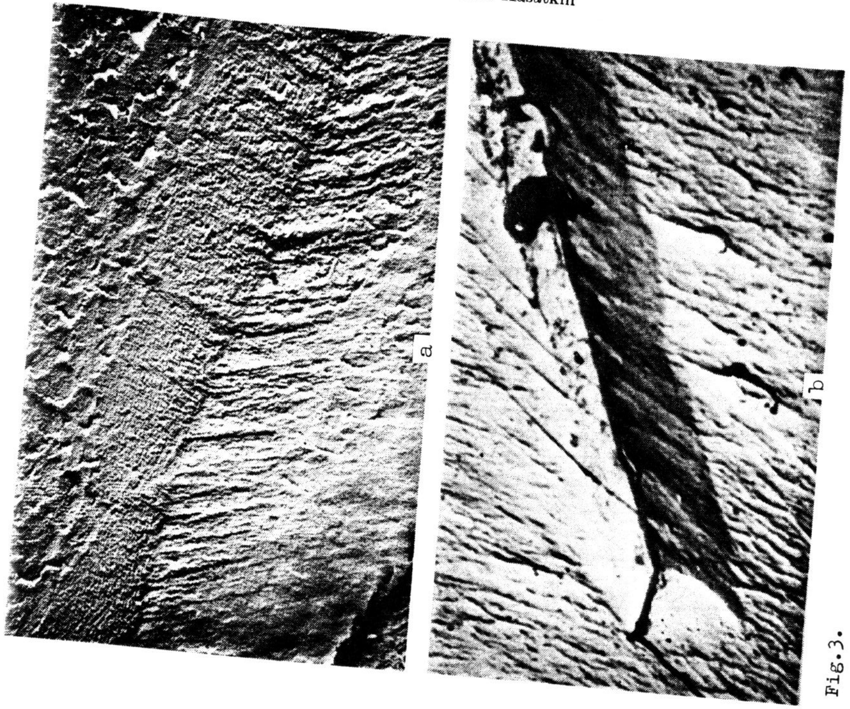
Fig.1. Fir-tree etching figures at the first type of deformation band in mild steel, x 900.



a

b

Fig.2.
Electron microphotographs of deformation bands of the first kind: a - etched after deformation, x 2800; b - etched before deformation, x 4000.



a

b

Fig.3.
Electron microphotographs of a wide deformation band of the first kind: a - etched after deformation, 4500X; b - etched before deformation, 1130X.

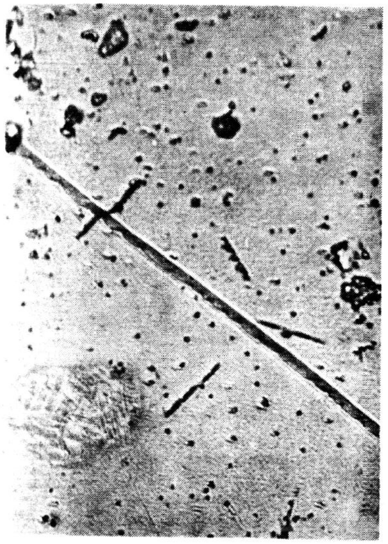
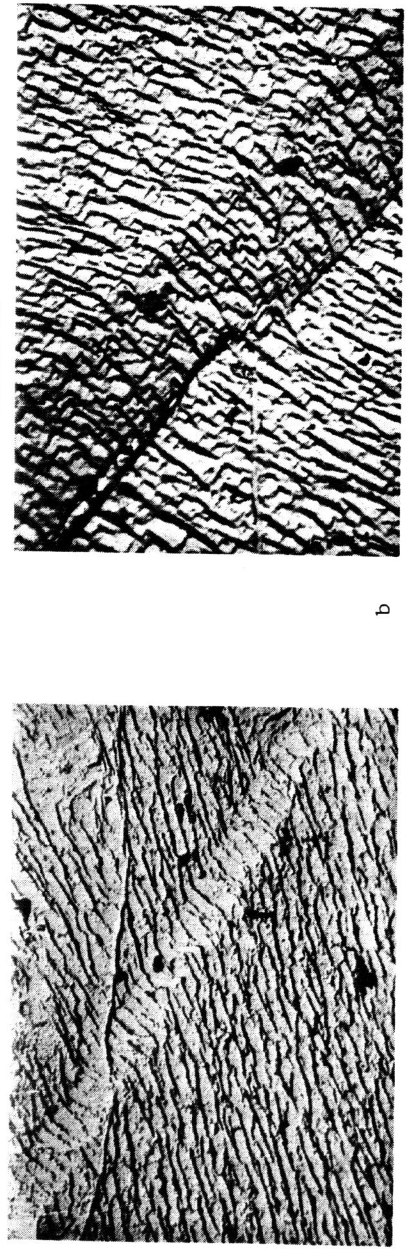


Fig.4.
Second kind of deformation band in mild steel, 260X.



b

a

Fig.5. Second type of deformation bands in mild steel: a - the band with comparatively smooth edges intersects a boundary between grains, 7400X; b - the band with steps formed as the result of the holding up local displacement in the bending zone, 6300X.

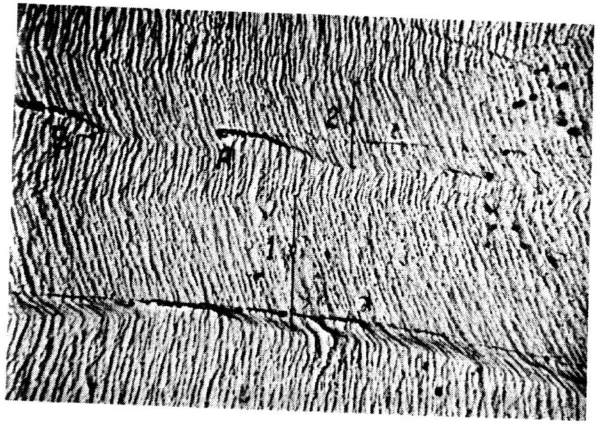


Fig.6. Two wide deformation bands of the second type (see parentheses 1 and 2). In band 1 local displacement can be seen in the bending zone along the whole length of the fixed sector of the band. In band 2 intensive local displacement can be seen at the bending line at the slag inclusions A and B 5000X.

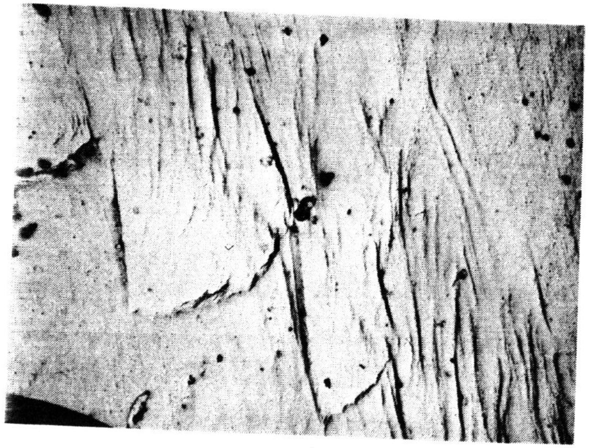
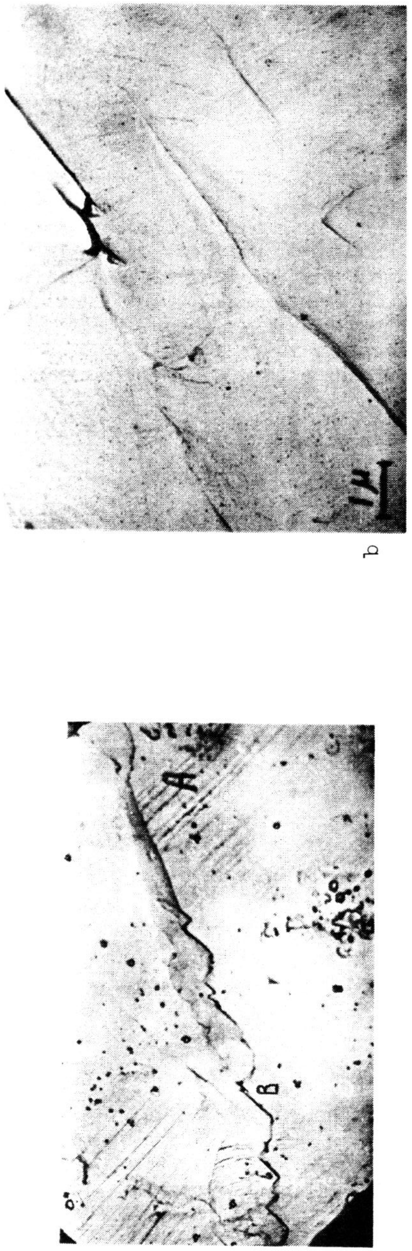


Fig.7. Wide second type deformation band with stepped boundary and transverse slip bands, 4900X.



b

a

Fig. 8.Second type of deformation band uneven in width with zig-zag edges: a - general shape of band A-sector with slip bands formed from steps 1600X; b - corner of a step with a tear in sector B x 9000.

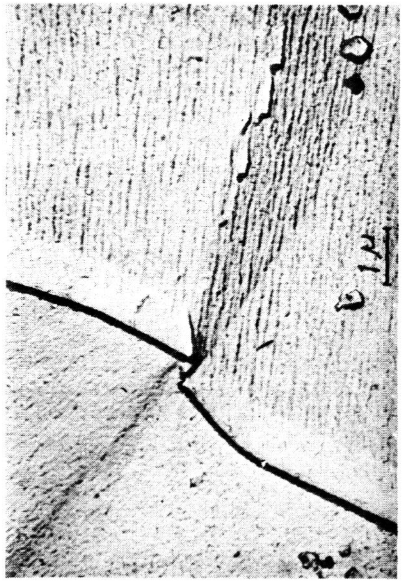


Fig.9.
Widge-shaped tip of second kind of deformation band "cuts" boundary between grains with high disorientation and passes into neighbouring grain x 9000.