INTEGRATED STRUCTURAL ANALYSIS OF INDIVIDUAL GRAIN PERFORMANCE UNDER PLASTIC DEFORMATION BY TEM, EBSD AND MICROHARDNESS MEASUREMENTS.

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In polycrystalline materials, individual grains may behave differently in accordance with their crystallographic orientation. As a result, many engineering properties depend upon the crystallographic textures which are developed in metals during industrial processing. In principle, the effects of orientation on microstructure can easily be studied in the TEM by using selected area electron diffraction in any given region of interest. For example, very different dislocation structures have been observed after plastic deformation in ferritic [1] as well as austenitic steels [2] as a function of grain orientation, as shown in Figs.1(a) and (b). Textures of commercial materials, however, are usually complex and include individual contributions of a very large number of grains. In such a situation, TEM observations alone are of limited value because of their well-known lack of statistical significance. The present paper shows how the problem of limited TEM statistics can be overcome by using TEM, EBSD and microhardness measurements as an integrated method of analysis, to explain the texture formation in electric steels.

Many electric steels develop their final properties during a decarburizing anneal which is usually preceded by a "skin pass" cold rolling reduction of 5 to 10%. It is generally believed that the stored energy introduced during the skin pass is responsible for the selection of certain preferred grain orientations which, during the decarburizing anneal, will grow by secondary recrystallization and thereby dominate the final texture. However, when investigating the dislocation structures produced by skin-pass rolling in the TEM, no clear effect of grain orientation was detected which could be used to quantify the effect of orientation on stored energy: Initial formation of a cell structure was observed in many different orientations as shown in Fig.1(c), making it difficult to determine dislocation densities which are supposed to control stored energy and which, according to the theories of plasticity, should depend on grain orientation according to the respective Taylor factors.

Previous efforts to confirm the effects of Taylor factors on the stored energy of cold work by using X-ray [3] and neutron diffraction techniques [4] have not been very successful. Much better results were now obtained by the integrated method of metallographic analysis, as shown below.

Not only the stored energy but also the hardness of a given ferrite grain can be expected to increase in proportion to dislocation density. Microhardness measurements were therefore taken from a large number of individual ferrite grains whose crystallographic orientation had previously been established by EBSD (electron back scattered diffraction) in an SEM. EBSD requires a well polished sample surface in order to generate high quality Kikuchi patterns, but a subsequent light metallographic etch was found to reveal grain boundaries and, at the same time, preserve the presence of the original ferrite grains under the light microscope, as shown in Figs.2(a) and (b). A "full constraint" Taylor model of plasticity was used to calculate the Taylor factors for all the grains which were monitored by EBSD. Microhardness values could thus be established for individual grains of known Taylor factor, as shown in principle by the hardness indentations in Fig.2(c), taken with a load of 2g.

Final results are presented in Fig.3 where it can be seen that, after 6% skin pass rolling, the microhardness increased with the Taylor factor as shown in Fig.3(a), whereas the hardness remained constant in the absence of plastic deformation as shown in Fig.3(b). The present results suggest that grains of higher Taylor factors (larger stored energy) may disappear during secondary recrystallization due to the preferential growth of grains of lower Taylor factors. In fact, recent texture studies appear to confirm this expectation [5].

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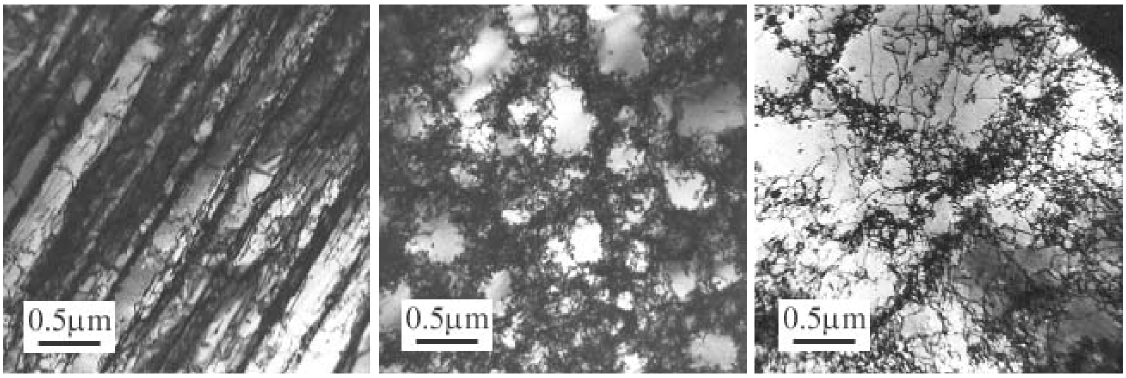
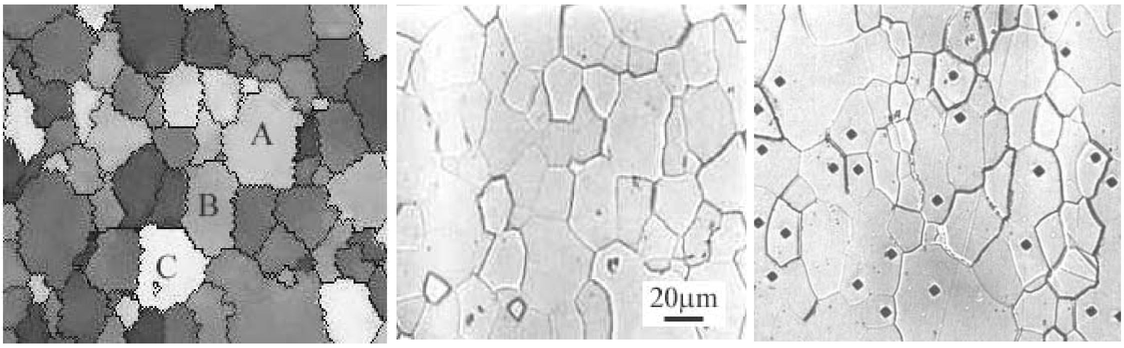


(a) (b) (c)

Fig.1: Dislocation substructures in the TEM. 10% tensile deformation of austenitic stainless steel with stress applied parallel to <110> in (a) and <100> in (b). 6% skin pass rolling of electric steel with {111} parallel to sheet surface in (c). Magnification 16.000 X.



(a) (b) (c)

Fig.2: Ferritic grain structure of electric steel after 6% skin pass rolling. Same area observed in the SEM by EBSD in (a), and by optical microscopy in (b). Example of microhardness indentations as seen by optical microscopy in (c). Magnification 250 X.

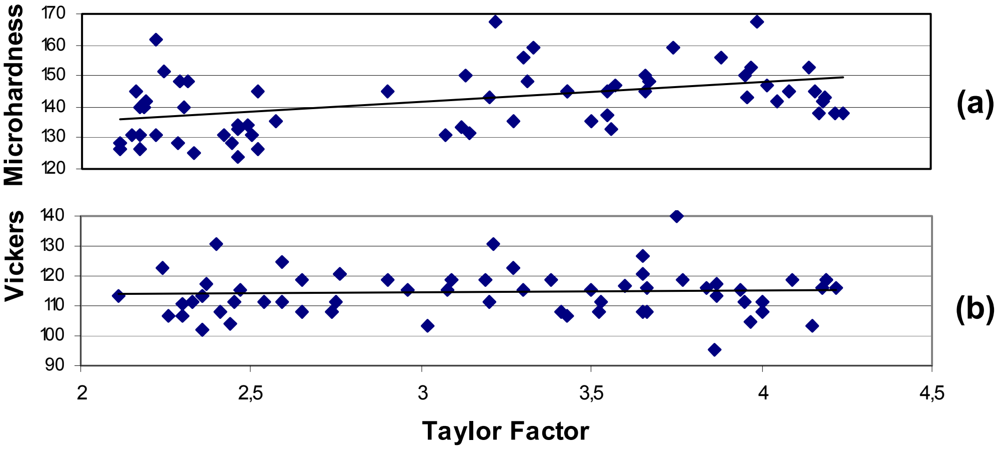


Fig.3: Microhardness measurements in individual ferrite grains of an electric steel as a function of grain orientation, represented by their respective Taylor factors. 6% skin pass rolling in (a), absence of plastic deformation in (b).