SLIPPAGE ALONG NONMETALLIC INCLUSION–MATRIX OF THE STEEL BOUNDARIES

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At high temperature grain boundary slippage makes a significant contribution to the total deformation of steel. Slippage along nonmetallic inclusion–matrix interphase boundaries in turn makes a contribution to deformation at the boundaries. If as slippage along intergranular boundaries is understood displacement of one grain relative to another along their common surface, then slippage on inclusion–matrix interphase boundaries consists of displacement of an inclusion and the matrix relative to one another along the interface as a result of shear deformation. It should be noted that the amount of slippage is not the same on interphase and intergranular boundaries [1].

The purpose of this work was investigation of slippage along steel matrix–nonmetallic inclusion boundaries for different types of inclusions since this question has received practically no attention in the literature.

The investigations were made of 08Yu, 08T, and 08Kh18N10T steels, which have a comparatively simple matrix at low and high temperatures, and also of NB–57 steel. All of the steels contained nonmetallic inclusions different in composition and properties [2]. Slippage along the inclusion–matrix boundaries was observed directly in high-temperature deformation by tension in vacuum on an IMASh–5S–65 machine when vacuum etching occurs revealing the deformation relief and making it possible to compare its development along the intergranular and interphase boundaries [3]. First polished surfaces, on which were applied bases of reference points for determination of the degree of deformation and marker lines, were prepared on the surfaces of the specimens. The specimens were first annealed at 1200°C, at which grain growth occurs and the dispersed aluminum or titanium nitride inclusions dissolve. On the specimens were selected intragranular inclusions coarse for the given steels (size 40–50 μm) through which were drawn scribe lines before deformation. The slippage is revealed experimentally in the formation on the polished surface of the specimen of a characteristic deformation relief as the result of relative displacement of the matrix and the inclusion and also in displacement (breaks) of the scribe lines during deformation. The measurements of displacements of the lines were made with a light microscope with an accuracy of 0.35 μm. For each type of inclusions measurements were made at a certain temperature at 10–15 particles. It should be noted that the lines rapidly disappear as the result of high-temperature vacuum evaporation and therefore to make the measurements and photograph them is extremely complex. In addition, the appearance of near-boundary deformation relief distorts the amount of displacement of the lines. It is known that use of lines for studying grain boundary slippage makes it possible to determine two of its components in the plane of the polished area while the vertical component is determined by other methods [1].

In this work the absolute amount of displacement of the lines was determined but it is necessary to develop a method of determination of all components of slippage for the case of nonmetallic inclusions.

The specimens were deformed in the 25–1200°C temperature range. The microstructure of the steels after vacuum etching was investigated with a Neophot–21 light microscope and a Tesla electron microscope. Foils and replicas with extracted particles of inclusions were prepared for electron microscopic analysis. The replicas were first studied under an MBS stereoscopic microscope, the particles of inclusions removed with a needle, and the place necessary for investigation marked. Figures 1 and 2 show the microstructures of the investigated steels after deformation at different temperatures.

In the 25–600°C range intragranular slip developed in the steels in deformation and it was localized close to the inclusions but signs of slippage along the inclusion–matrix boundaries were not observed. At 700–900°C slippage occurred along the grain boundaries, weakly
Fig. 1. Nonmetallic inclusions in 08Yu (a-d, g), 08T (e), and NB-57 (f) steels after deformation at different temperatures (800×): a) MnO·Al₂O₃, 700°C, ε = 12%; b) MnO·SiO₂, 700°C, ε = 18%; c) MnO·Al₂O₃, 1100°C, ε = 12%; d) Al₂O₃, 1100°C, ε = 20%; e) TiCN, 1100°C, ε = 32%; f) FeO(Fe, Mn)S, 1100°C, ε = 15%; g) MnO·SiO₂, 1100°C, ε = 34%.

at 700°C and increases intensely with an increase in temperature. Slippage was not observed close to the inclusions, which is indicated by breaks in the lines at the grain boundaries and the absence of it close to the inclusions (Fig. 1a). If an inclusion was located at a grain boundary, it made intergranular slippage difficult. Brittle fracture of the inclusion occurred and the direction of the cracks coincided with the grain boundary (Fig. 1b, shown by an arrow).

Slippage along the inclusion-matrix boundaries was observed at 1000-1200°C. It was revealed in widening of the interphase boundaries (Fig. 1b-d) and the appearance of a deformation relief similar to the structure of the intergranular boundaries (Fig. 2a) is confirmed by the presence of breaks in the lines close to the inclusions (Fig. 1c, f). Close to the inclusions, as at lower temperatures, localization of intragranular deformation was observed. As a rule the deformation relief around the inclusions appears in the whole interphase boundary. It must be distinguished from the voids which are ductile cracks formed close to inclusions as the result of failure of continuity at the interphase boundaries [2]. The voids are elongated in the direction of tension and appear first at the side surfaces of the inclusions.