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Influence of Lamellar Direction in Pearlitic Steel Wire on Mechanical Properties and Microstructure Evolution

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Abstract: During cold drawing of pearlitic steel wire, the lamellar structure becomes gradually aligned with the drawing axis, which contributes to the ultra-high strength. A direct simulation about the mechanical behaviors and microstructural evolution of pearlitic lamellae was presented. A representative volume element (RVE) containing one pearlitic colony was established based on the real transmission electron microscope (TEM) observation. The deformation of pearlitic colony during tension, shear and wire drawing were successfully simulated. The numerical results show that this metallographic texture leads to a strong anisotropy. The colony has higher yielding stress when the lamellar direction is parallel and perpendicular to the tensile direction. The lamellar evolution is strongly dependent on the initial direction and deformation mode. The formation of typical period shear bands is analyzed. In the wire drawing, the pearlitic colony at the sub-surface experiences a complex strain path: rotation, stretching along the die surface, and rotation back.

Key words: pearlitic lamellae; steel wire; drawing; mechanical property; representative volume element

Heavy drawn pearlitic steel wire has the highest strength among all steel products. Thus, it is widely used in industry, such as automobile tires and silicon pellet cutting[1,2]. In the past decades, many efforts have been done in exploring its hardening mechanisms during wire drawing[3-6]. It is well accepted that the high strength is attributed mainly to the refinement of lamellar structure and anisotropy[7,8].

The anisotropy mainly results from a strong <110> fibre texture parallel to the drawing direction[9-13] and a lamellar alignment[14-16]. Nam et al. [17] found a progressive alignment of lamellae along the drawing axis with increasing drawing strain. When strain reaches 1.5, almost all lamellae are parallel to the drawing direction. The lamellar evolution has been investigated by many researchers including period shear bands[18,19] and cementite dissolution[1,20,21]. Zhang et al. [16] studied the deformation of cementite over a wide range of cold drawing strain. It was found that the cementite can deform plastically. And a theory for lamellar alignment with different initial morphologies and directions during drawing was proposed.

Unfortunately, all the investigations above were based on the discrete observations of deformed lamellar structure. Kapp et al. [22] applied in-situ observation on the pearlitic lamellae of micro pillars during compression and found that the deformation and localization mechanisms vary with the lamellae direction. However, the investigation of the mechanical properties and the lamellar evolution of individual pearlitic colony is still not enough, particularly with arbitrary lamellar direction and during wire drawing. In this study, a representative volume element (RVE) based on the real observations of lamellae was established to investigate the influence of the lamellar direction on the mechanical properties and microstructural evolution in tension, shear and wire drawing.

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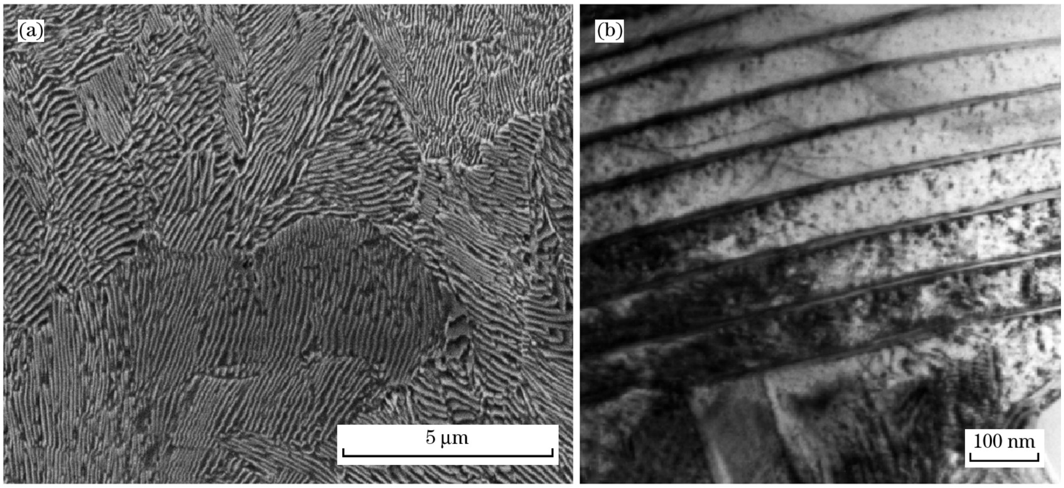
1 Experiment and Results

The pearlitic steel wire samples were supplied by NV Bekaert SA. The chemical composition is Fe-0.8C-0.18Si-0.5Mn (mass%). The as-received samples (diameter: 0.83 mm) were processed to obtain the pearlitic microstructure. Then, the samples were drawn in 3 passes up to 42% area reduction without heat treatment. The equivalent strain was 0.55.

Scanning electron microscopy (SEM) was used to examine the lamellar structure of as-received and deformed pearlitic steel wire. It was carried out on a FEI Nova Nano microscope. The selected positions for observation were on the longitudinal section. Standard grinding, polishing and electro-polishing in turn were applied to prepare the samples. The electro-polishing condition was 15 V, −20 ℃ and 8 vol.% perchloric acid in ethanol. Transmission electron microscopy (TEM) was used to capture lamellar configuration and dislocation arrangement in ferrite. The positions for observation were also on the longitudinal section of wires.

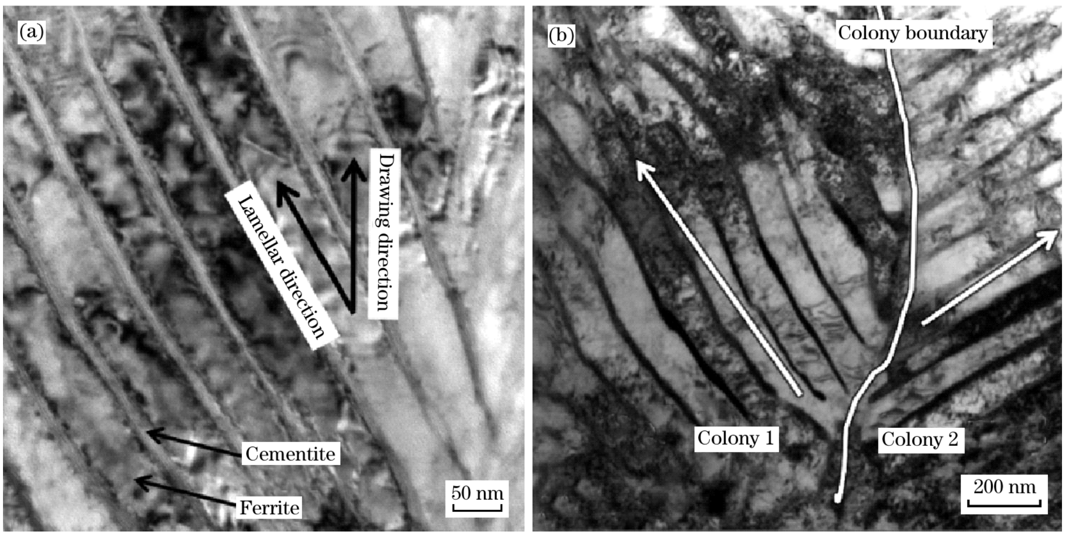
The SEM micrograph of the as-received pearlitic steel wires is given in Fig. 1(a)[23]. It consists of many pearlitic colonies. Every colony consists of two phases: cementite (light) and ferrite (dark). The lamellar structure and dislocation arrangement were observed using TEM, shown in Fig. 1(b). The ferrite is parallel to the cementite. The lamellar spacing is about 90 nm.

The lamellar direction is defined in Fig. 2(a). It can be expressed by the angle between the lamellar di-



(a) SEM micrograph; (b) TEM micrograph.

Fig. 1 Pearlitic structure of pearlitic steel wires



(a) Single colony; (b) Two colonies.

Fig. 2 Lamellar direction in pearlitic colony