Effects of Banded Structure on Fasteners (Part 1)

紧固件中的带状组织研究与控制（上）

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1. Proposed Questions

With the development of the automotive industry, especially new energy vehicles and technology improvement, the mechanical properties of fasteners have been increasingly emphasized. The mechanical properties of general fasteners include yield ratio, hardness, fatigue life, and other key indicators, of which the fatigue life is the most direct response to the physical properties of a fastener under external loading.

In the production of fasteners, after the use of a batch of raw materials, it is inevitable that another batch of raw materials will be used. The composition of raw materials from different steel mills and different furnace lot numbers of the same steel mills is different, and such a difference will lead to a serious impact on the quality of heat treatment. Even the same material grade, specifications and performance of products with different furnace lot numbers (in the same process), processed with the same equipment and heat treatment, will appear inconsistent tensile strength, hardness value and deformation, and may even appear serious deviation or quench cracks. Hence, it is necessary to make corresponding adjustments in the heat treatment process for products of different furnace lot numbers.

Low alloy steel is one of the key materials widely used in automobiles, railway, engineering machinery, etc. It is an important raw material to ensure the safety of core component connection. **"Band" is a common harmful structure of low alloy steel. Common band types are ferrite/pearlitic, ferrite/martensitic, etc.** In terms of low alloy steels, band generally refers to ferrite/pearlitic structure formed under slow cooling of hot rolling (see **Fig. 1**).

▲ Fig. 1 Ferrite/Pearlitic Structure

According to the formation mechanism of banded structure, it can be divided into primary banded structure (caused in the solidification process of steel due to selective crystallization and dendritic segregation) and secondary banded structure (which is caused in the heat treatment of steel and is parallel, layered, strip-like along the machining direction). **Banded structure is a common structural defect formed in the hot rolling process of coil and bar billets, which seriously affects the subsequent processing and performance of the steel.**

In the automotive industry, there is no need for control of banded structure in high grade bolt steels. However, the conditions, control requirements and rationale for its creation need to be reasonably understood and are discussed below:

Micro segregation of alloys is the reason for the formation of banded structure, and reasonable control of alloy composition, dendritic morphology and thermal processing technology is also an important way to inhibit banded structure. The larger the temperature difference between the Ar3 region transformation within and between the dendrites caused by micro segregation, the easier the formation of banded structure. The cooling rate and grain size during austenite decomposition are the main factors influencing the formation of banded structure, and higher cooling rate and larger grain size will inhibit the occurrence of banded structure.

There are two general reasons for the formation of banded structure:

① Banded Structure Caused by Component Segregation

In terms of low carbon bolt steel, when more impurities exist, processing deformation will result in the streamlined distribution of impurities. When the steel cools from the heat processing temperature, these impurities can be used as the core of the nucleation of the proeutectoid ferrite, which will generate around the impurities first, while the remaining austenite will turn into pearlite, making proeutectoid ferrite and pearlite distribute in bands, thus forming banded structure, which is difficult to eliminate by heat treatment.

② Banded Structure Caused by Improper Heat Processing Temperature

In forging, when the forging-stopping temperature of the medium carbon alloy bolt steel is in the phase between Ar1-Ar3, ferrite will precipitate from the austenite in the form of bands along the direction of metal flow, and the austenite which hasn't decomposed yet will be cut into bands. When the temperature cools down to Ar1, the austenite will be transformed into banded pearlite, which can be eliminated by normalizing or annealing.

The existence of banded structure will make the mechanical properties of bolt steel anisotropic, and those along the banded structure will be obviously better than those perpendicular to it. Materials are prone to crack from the junction during the forging process. Since the banded structure is different from the adjacent microstructure, there are also differences in performance, and the uneven distribution of stress between the strong and weak bands will result in the overall reduction of mechanical properties, especially the significant reduction in the plastic toughness of the bolt steel; the anisotropy of structure and performance is prone to lamellar tearing along the banded structure under external force, often laying a hidden danger for the early failure of bolts.

2. Current Conditions and Difficulties

2.1 Research on Current Conditions

Since there is a lack of research on automotive fastener banded structure in China, banded structure should be the industry's attention in view of its increasing impact on the production and performance of steel. Banded structure in high-end fasteners used in the aviation/aerospace, marine engineering, advanced rail transportation, and other key areas should especially receive urgent attention. Comment on the solutions of formation, hazards, and control of banded structure in common fastener steel, and raise key issues in the study and control of banded structure.

The banded structure of steel for fasteners can only be evaluated visually in the annealed equilibrium state (see **Fig. 2**). **Fig. 2** shows the banded distribution of ferrite/pearlitic 45 steel.

▼ **Fig. 2 45 Steel Ferrite/Pearlitic with Banded Distribution**

The more serious the banded structure is, the more serious the alloy segregation is, and the hardenability varies greatly in different areas. Large-size bolts after head forging, if not annealed or normalized, will be prone to granular bainite organization and thus affect the mechanical processing performance; in addition, during the quenching process of bolts, the hardenability of the areas with low alloy content (ferrite banded areas) is lower, making it hard to guarantee the quality of quenching. The core of the bolt is prone to banded hardened bainite, resulting in greater fluctuations in tensile loading, affecting the stability of the mechanical properties. In short, the quality of the relevant heat treatment technology of fasteners has a significant impact.

During the cooling process, the first ferrite precipitation area is where the austenite is relatively unstable. Such a unstable condition is due to the low alloy content in the region. The pearlitic region with the high alloy content will lead to stable austenite. The relative content (%) of ferrite and pearlite depends on the carbon content of the material. At the same time, to promote the uniform diffusion of alloys and reduce the micro segregation in the solidification structure of coil, bar and billet is the main way to reduce or eliminate the banded structure. Elongated inclusions may be present in the banded structure, however, the effect of the size, morphology and distribution of inclusions in the steel on the banded structure has not been clear so far. The detailed characterization and quantitative evaluation of banding and its harmful effects are important tasks that need to be carried out urgently. In addition, the influence of the heating system of coil and bar billets on the elimination of banding and the control of the grain size also needs to be studied.