論文の内容の要旨

論文題目　Microstructure Control of Cr-V-Mo Steel by Semi-Solid Processing
(Cr-Mo-V鋼の半溶融処理による組織制御)

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The aim of the present thesis is establishing a shorter and more energy-efficient process chain for manufacturing of high-quality tool steel products to replace conventional multi-pass rolling method, as long time and large energy is spend in the conventional route. Semi-solid processing technology, as an innovative forming technology of metal and alloys, was selected as the core technology to establish our innovative routes for manufacturing of high-quality tool steel products. Various semi-solid forming routes of ferrous alloys and the characteristics of semi-solid processed ferrous alloys were discussed. Ferrous alloys exhibit distinctive microstructure and characteristics in semi-solid state. In consideration of the spherical microstructure and flexible forming property of metals in a semi-solid state, semi-solid processing technology can improve the conventional route and shorten the process chain of tool steel products manufacturing.

Partial melting behaviors of commercial SKD61 tool steel and cast Cr-V-Mo steel were investigated experimentally. Based on the experimental results, a clear and complete understanding of the morphologies (including size of solid particles and liquid fractions) and deformation characteristics (including forming stress and liquid segregation) of ferrous alloys at various temperatures was obtained. Aiming at realizing the spherodization of semi-solid state tool steel, various methods were introduced and discussed. In consideration of the tool life and simplification of equipment, recrystallization and partial melting (RAP) method was selected to achieve the refinement of tool steel. Two innovative routes for manufacturing of

high-quality tool steel products were proposed based on RAP method. The refinement of the microstructure and the homogeneous distribution of alloying elements are crucial for realizing such a short process, which can be considered as “semi-solid thermomechanical processing”.

With the aim of investigating and verifying the feasibility of manufacturing tool steel products with excellent mechanical properties using improved route, RAP processing was studied systematically. As the definition of RAP, this processing includes two main stages, predeformation stage and partial melting stage. The main parameters of predeformation include predeformation degree and predeformation temperature. The main parameters of partial melting includes heating rate and isothermally holding time. The effects of parameters such as predefomration temperature, predeformation degree, heating rate, and holding time on the microstructure and mechanical properties of cast Cr-V-Mo steel were studied experimentally. Recrystallization, austenization, grain growth and partial melting occur during heating of predeformed cast billet. These behaviors refine the microstructure and improve the mechanincal properties. The refinement of microstructure and improvement of mechanical properties become more significant, when RAP is conducted with larger predeformation (50%), higher heating rate (50 °C/s) and shorter isothermal holding time (20 s).

According to the innovative route proposed in our study, subsequent heating treatments are quite important to adjust the mechanical properties of the ferrous alloy products processed by semi-solid processing. With the aim of improving the quality of semi-solid processed products, the optimal subsequent heat treatment strategy for semi-solid processed Cr-V-Mo steel was investigated. The effects of final heat treatments including quenching and tempering on the microstructure and mechanical properties of RAP processed Cr-V-Mo steel were clarified experimentally. The phase segregation of RAP-processed specimen results in an inhomogeneous microstructure and unstable hardness that cannot be improved by only quenching. Subsequent tempering treatment leads to the release of microstress, the diffusion of alloying elements, and changes in the morphology of carbides. This microstructural evolution results in more stable hardness and better ductility of the tempered specimens. When the tempering temperature is about 560 °C, secondary hardening occurs and a good combination of hardness and strength is obtained.