Application and Progress of Microstructure and Mechanical properties Control Methods for Ultra-High Strength Steel in Rolling Process

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Abstract. This paper introduces traditional ultra-high steels and the dilemma of its processing, the application of the rolling method in the production of ultra-high strength steel, Nano-fine grain preparation techniques for improvement of strength and toughness, Phase composition regulation to improve mechanical properties. Summed up microstructure and mechanical properties control methods for ultra-high strength steel in the rolling process, Using the methods innovatively solves the flexible rolling process produces 1600 MPa grade ultra-high strength and toughness nano-scale B/M complex phase under the existing equipment conditions of ordinary steel enterprises.

1. Introduction
Ultra-high strength steels (UHSS) can reduce steel consumption and improve the safety coefficient so significantly that it is widely used in the field of rocket engine casing, aircraft landing gear, and other special military industries[1]. However, the traditional UHSS is challenging to be smelt as result of a high alloying addition and complex compositions (such as low alloy super high strength steel 300M and 4340Ni[2], its total alloy mass percentage are above 1.8%[3]). The subsequent manufacture processes, which include casting, forging, and quenching and tempering treatment[4] are much complicated. Accordingly, the strength is sometimes challenging to match the toughness, and eventually, the steels exhibit high strength and low toughness. Also, lengthy production process, high energy consumption, high cost, small batch production are unfavorable factors for the UHSS [5-7]. It is urgent to provide a new reduced composition and development of a more efficient process for UHSS production.

2. Microstructure and Mechanical Properties Control Methods of UHSS
2.1. UHSS Materials in Rolling Process
The mechanical properties of traditional medium/high carbon UHSS are mostly controlled by introducing MC carbide particles into high carbon flake martensitic matrix to perform fine grain strengthening and precipitation strengthening, finally, achieve ultra-high strength. However, strength and toughness can hardly simultaneously preform the high level, toughness and weldability deteriorate. Since forged piece subjected single principal stress on the low temperature, according to the Tresca Yield Criterion, the material is more difficult to deformed. If the compressive stress is further increased, the low-melting eutectic tends to initiate cracks at the boundary of the matrix,
resulting in cracking of UHSS during the hot deformed process. So the hot deform process at a high temperature (about 950–1000 °C) austenite recrystallization zone. Although the process can be controlled by high temperature austenite recrystallization process to refine the primary austenite grains of casting billet, the austenite hardening morphology and strain induced precipitation cannot be controlled in austenite non-recrystallization zone (about 720–950 °C). As a result, dislocation recovery in the hardened austenite or even recrystallized austenite grows up at the high temperatures in the subsequent process. Besides, the martensitic transformation is a non-diffusion, and no random walk or sequential jump is crossing the interface during the transition. Therefore, the nucleation position of martensite is relatively small, the long axis is long, and the interlayer spacing is wide. Consequently, primary austenite could not be parted into cluster segments by the martensite.

Although a large amount of MC dispersion precipitation could increase the strength of UHSS, it tends to result in higher strength, poor toughness and deteriorated weldability. Compared with traditional C-Mn high strength steel, Cr-Mo bainitic UHSS with the characteristics of “lower carbon or alloy content, fine grain, Nano-precipitate phase, excellent weldability, and good toughness matching.” The advantages are as well as the fine needle-shaped/blocky bainite and the Nano-precipitated phase in a wide cooling range (5–20 °C/s) [8, 9]. The strength and toughness are well-matched and have the inherent characteristics for the reduction production process.

2.2. Nano-Fine Grain Preparation Techniques for Improvement of Strength and Toughness
Fine-grained strengthening uses grain refinement to increase the grain boundary area, thereby hindering the dislocation movement and significantly improving the strength and toughness. It is an essential method for the strict control of ultra-high strength steels. At the same time, the fine-grain strengthening method can significantly reduce the amount of alloy, and reduce the carbon equivalent to provide technical improvement space for the design of the reduced component system and the improvement of welding performance. Umenoto et al. [10] summarized the grain size range that can be obtained by various grain refinement methods such as traditional Thermal Mechanical Control Processing (TMCP) rolling with massive reduction rate in low temperature, Equal Channel Angular Pressing (ECAP), Accumulative Roll Bonding (ARB), and Severe Plastic Deformation (SPD). Austenite grain refinement is the basis and prerequisite for the final α phase refinement. The deformation heat treatment process is the modulation method organically combines deformation, solid phase transformation, and recrystallization. Among the process, Strain Induced Ferrite (SIF) and microalloying elements play an essential role in the inhibition of recrystallized austenite growth and the proliferation of deficient structures in hardened austenite. The above experimental reveals the potential feasibility of deformation heat treatment for the preparation of Nano-fine grain UHSS.

2.3. Phase Composition Regulation to Improve Mechanical Properties
Traditional UHSS are generally multiphase structures composed of ferrite, bainite, martensite and retained austenite. Ferrite is a soft phase that can coordinate deformation during stretching; Bainite can increase the strength of steel; austenite transforms into martensite when loaded at room temperature, which produces phase change induced Transformation Induced Plasticity (TRIP) effect [11]. The beneficial effect of retained austenite on improving the plasticity of UHSS is necessary to systematically study the influence of retained austenite on the plasticity and explore the structure influence factors for the improvement of plasticity. At the same time, the stability of retained austenite is the key to determine whether it can remain to room temperature and play a role in deformation.

2.4. Comprehensive Performance Evaluation of Experimental Steel
This paper innovatively solves the flexible rolling process under the existing equipment conditions of ordinary steel enterprises and produces 1600 MPa grade ultra-high strength and toughness nano-scale B/M complex phase in the hot rolling process. As shown in Figure 1, this research results of this paper have essential engineering application value. The influence of rolling parameters on the regulation of nano-fine grain toughness is revealed. The method of phase-change induced toughness control to prepare B/M complex super-high strength steel is obtained. The results of this paper can be applied to the process design and research and development of other ultra-high strength and tough metal
materials, also provide forward-looking theoretical support for the production and promotion of economical low-alloy ultra-high strength steel.

Figure 1. EBSD(a), TEM(b) and Characteristics(c) of mechanical property for this novel steel

3. Conclusion
(1) Using The traditional forging processes, the strength and toughness of UHSS can hardly simultaneously preform the high level, toughness and weldability deteriorate. The advantages of Cr-Mo bainitic UHSS have the inherent characteristics for the reduction production process.

(2) The retained austenite in UHSS can be coherently deformed, effectively enhancing the deformation ability of the martensite; The stability of retained austenite in room temperature is mainly related to its chemical composition, morphology, distribution of surround phases and stress states and other factors are related.

(3) This paper innovatively solves the flexible rolling process under the existing equipment conditions of ordinary steel enterprises and produces 1600 MPa grade ultra-high strength and toughness nano-scale B/M complex phase in the hot rolling process.

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