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Development of the third generation advanced high strength steel for automobile

Liu Bo [1,a],Dai Yuehong[1,b], Huang Xiaoyan [2, c], Wang Yue [2,d]

[1]Zhenjiang College, Zhenjiang,Jiangsu,China 212003

[2]Army Military Transportation College Zhenjiang Campus, Zhenjiang, Jiangsu, China 212003

[a]zjgzliubo@163.com, [b]105010155@qq.com, [c]hxylyd@163.com, [d]wangyue2016@163.com

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Abstract: In order to meet the needs of the development of automotive lightweight,a lot of advanced high strength steels are developed.The first generation of advanced high strength steel is very low in the strength-elongation product, lightweight and security.The cost of the second generation steel is high and the technology is poor.The third generation of advanced high strength steel is deeply concerned by the automotive manufacturing industry due to its high strength,high toughness and good formability.In this paper, the research status of the third generation advanced high strength steel are introduced, such as Q&P steel, medium Mn-TRIP steel and TBF steel.

Introduction

In recent years, the automobile industry is facing increasingly serious energy, environment and safety problems.It is the key for automobile manufacturers improving the competitiveness to reducing auto weight, reducing energy consumption, noise, reducing exhaust emissions and improving the safety of collision avoidance. With the improvement of vehicle lightweight and collishion safety requirements, advanced high strength steel(AHSS) is developed rapidly and is developing towards high strength and high plasticity.The strength-elongation product (tensile strength multiplied by elongation) has become an important index to measure the performance of automobile steel. At present, advanced high strength steel for automobile can be divided into the first generation, the 2nd generation and the third generation.The strength-elongation product of the first generation AHSS is less than 15GPa · % and lightweight and security are very low.The strength-elongation product of the second generation AHSS is 50-70GPa · %. Because of high alloy content, complex process and high production costs, it is difficult to be accepted by the market for the second generation AHSS. The strength-elongation product of the third generation AHSS is between 20GPa · % and 40GPa · %[1],its lightweight and security are higher than those of the first generation automobile steel,its production cost is lower than that of the second generation automobile steel.

The third generation AHSS has become the focus of research and development in the world due to its good performance price ratio. In this paper, the research status of three types of the third generation AHSS are introduced.

Quenching and carbon partitioning steel

Production process of Q&P steel

Q&P steel is a new generation AHSS. Through quenching-partitioning technology Speer and others were developed Q&P steel on the badid of Fe-Si-Mn baded TRIP steel[2-3].The microstructure

of Q&P steel is made of martensite and a certain amount of retained austenite .Martensite provides high strength and retained austenite provides high plasticity. A schematic diagram of the typical heat treatment process of Q&P steel is shown in Figure 1. The principle of heat treatment process is as follows. Firstly,heat the steel to austenitizing area (or two-phase region)and make it isothermal for a period of time.Secondly, cool rapidly to certain temperature between Ms(martensite start) point and Mf(martensite finish) point and make it isothermal quenching to get martensite and a certain amount of austenite.Then heat to partitioning temperature above Ms point and keep the temperature for a period of time to ensure retained austenite get more carbon.

The room temperature microstructure of Q&P steel is mainly poor carbon lath martensite and rich carbon retained austenite. Martensite ensures steel.strength.Retained austenite increases plasticity due to transformation induced plasticity during deformation. So the strength of steel can reach 1500 Mpa and corresponding elongation still has 15%.

Key technology of Q&P steel production

The key to the production of Q&P steel is to control heat treatment temperature, including annealing heating rate, annealing temperature and time, cooling speed and temperature of slow cooling section, quenching-cooling speed and temperature, partitioning temperature and time.

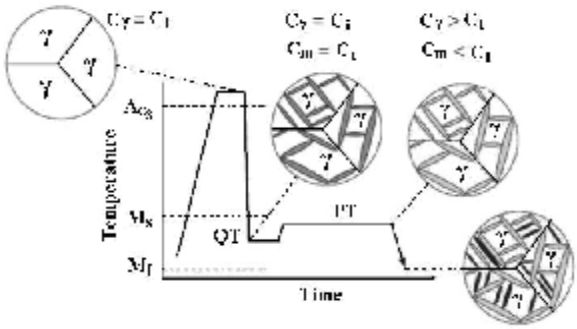


Fig 1 Schematic illustion of Q&P heat

In the production of Q&P steel, it is favorable for introducing ferrite, stabilizing austenite and increasing elongation through high heating rate, annealing in two-phase region, low slow cooling speed and temperature. Martensitic microstructure is obtained by fast cooling speed to ensure high-strength of Q&P steel.

Medium Mn-TRIP steel

Design idea of medium Mn TRIP steel

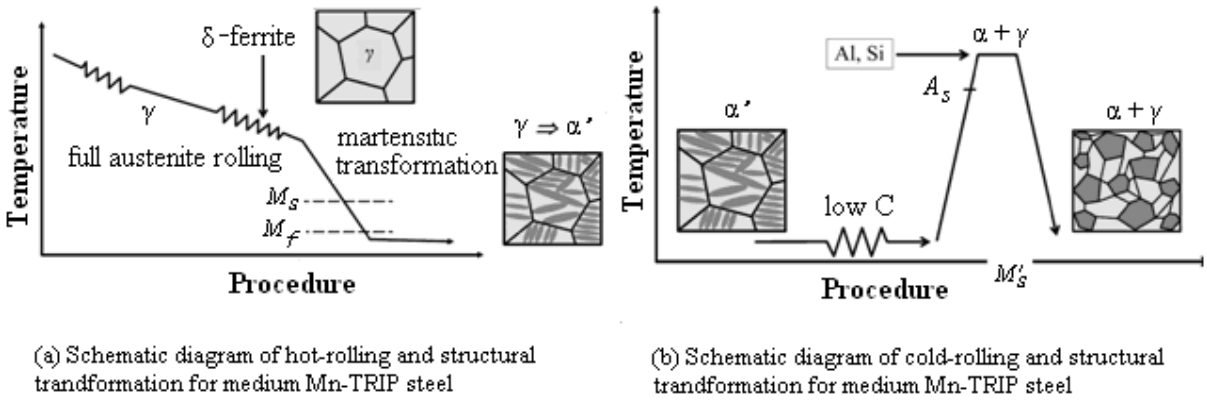
Whether TRIP steel of the first generation automotive steel or Q&P steel of the third generation automobile steel,they have a common feature. That is to make austenite get rich carbon to stabilize austenite by carbon partitioning. Then the higher plasticity is obtained by the austenite TIRP effect at room temperature. Depending on the carbon partitioning, a large amount of metastable austenite can be obtained when the steel contains high carbon. If the carbon content in the steel is up to more than 0.4%, it will significantly deteriorate the welding performance of the steel. Therefore, it is very limited to regulate and control the metastable austenite phase only by carbon partitioning. So the austenite content in the ordinary TRIP steel and the Q&P steel is generally less than 15% and the content of the metastable phase can not be controlled to a higher level.

Medium Mn-TRIP steel adopts the idea of compound partitioning and metastable controling to get high strength and high plasticity automobile steel and uses the principle of reverse transformation and carbon and manganese composite partitioning to control the metastable austenite content. Through meduim manganese alloying, carbon and manganese are partitioned to austenite during reverse transformation to form the complex structure made of body centered cubic ferrite and face centered cubic retained austenite. The grain size of ferrite matrix and retained austenite are submicron. The content of metastable austenite can be up to 20%-40%.

Production process of medium Mn TRIP steel

The current production technology of medium Mn-TRIP steel is :hot rolling→cold rolling →reverse phase transformation annealing, The schematic diagram is shown in Figure 2[4]. Due to

high content of manganese, hot rolling microstructure is martensite. When cold rolling the martensite deforms to produce a large mumber of nucleation points due to internal distortion.Subsequently in the annealing process, deformation martensite reverses transformation into ultrafine ferrite and austenite. Different from cooling process of the traditional TRIP steel after the strict intercritical heating, medium manganese steel has no special requirements on the cooling rate. Reverse transformation annealing is controled in the two-phase region. Ferrite -austenite microstructure obtained in the two-phase region can be stably retained at room temperature. The mass fraction of manganese in steel is in the middle and low range (4%-8%).The volume fraction of retained austenite in the matrix is generally less than 50% after revers transformation.Because of its low stacking fault energy, the deformation is not enough to form a TWIP(twinning-induced plasticity) effect and TRIP (trandformation-induced plasticity) is main plastic deformation mechanism.



(a) Schematic diagram of hot-rolling and structural trandformation for medium Mn-TRIP steel

(b) Schematic diagram of cold-rolling and structural trandformation for medium Mn-TRIP steel

Fig 2 Schematic diagram of hot-rolling and annealing for medium Mn-TRIP steel

Blooming temperature of medium manganese steel is controlled in 1150-1125˚C and finishing temperature is controlled in 800-930˚C . This means that the temperature control system for hot rolling of medium manganese steel is not very different from that of common steel. It can be processed by a conventional hot rolling mill. The reverse transformation annealing is a necessary new process for medium manganese steel and its annealing temperature is between 575˚C and 800˚C .

TBF steel

Production process of TBF steel

Figure 3 is a typical rolling and continuous annealing diagram for TBF (TRIP aided bainitic ferrite)steel. TBF steel will austenitize completely when heated and kept at 950˚C . The average C and Mn content of austenite is relatively low .Then TBF steel is rapidly cooled to bainite region and a large number of austenite is transformed into bainite and expel carbon to untransformed austenite. During the cooling after isothermality, the unstable austenite is transformed into martensite and the stable austenite is retained to room temperature. During the continuous annealing, the bainite isothermal temperature has a significant effect on the microstructure and properties of

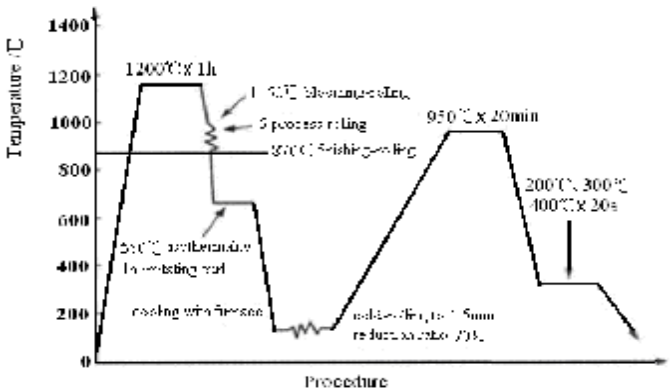


Fig 3 Schematic diagram of typical rolling and continuous

TBF steel. When the bainite isothermal temperature is 300˚C , TBF steel has low yield strength (789 MPa), high tensile strength (1241MPa) and good elongation (16.6%). The main reason of low yield strength is due to the formation of 80~190 nm carbide-free bainitic lath. After the determination of XRD (X-ray Diffraction), the retained austenite content is 12.04% and the carbon content of the retained austenite is 1.4%. Stable bulk retained austenite and carbide-free bainitic lath are beneficial to the improvement of toughness. On the contrary, martensite should be reduced or avoided as much as possible.

Microstructure and property of TBF steel

The microstructure characteristics of TBF steel are fine regular carbide-free bainitic ferrite strip, thin film retained austenite and massive retained austenite distributed on bainitic-ferrite matrix and very few tempered martensite.

High toughness of TBF steel is mainly due to its fine regular lath structure, TRIP effect of rich carbon retained austenite and the long range internal stress of untransformed thin film retained austenite.

Because of the existence of metastable retained austenite (volume fraction of 10%-30%) in TBF steel, it has not only excellent strength and plasticity matching, but also higher fatigue strength, better impact performance, flanging and reaming performance. The typical microstructure of TBF steel is shown in Figure 4.

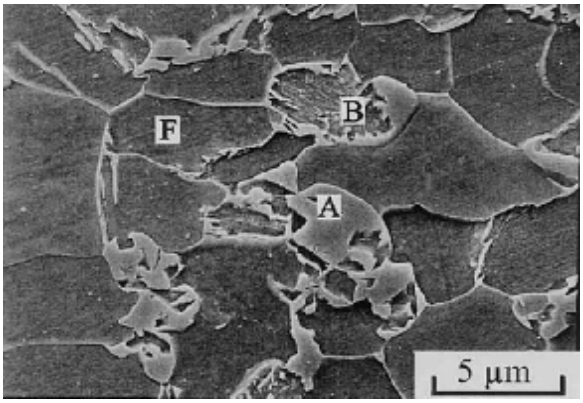


Figure 4: SEM micrograph of TBF steel F-proeutectoid ferrite, B-carbide-free bainite,

Acknowledgements

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