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NEW DEVELOPMENT OF HSLA STEELS IN CHINA

ZHANG Xiao-gang [1], YANG Cai-fu [2], SHANG Cheng-jia [3]
1. The Chinese Society for Metals, Beijing, PR China;
2. Central Iron and Steel Research Institute, Beijing, PR China;
3. University of Science and Technology Beijing, Beijing, PR China

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Abstract

During the last decade, the adjustment and upgrade of steel product structures always be very important tasks in China's iron and steel industry. Since there is a fast growth of steel production in China, a series of research achievements in the technology area of HSLA steels have been made and applied successfully in the actual production, and thereby promoted a rapid development and application of China's HSLA Steel products. However, The China's iron and steel industry is now facing the excess production capacity and under pressure from respects of resource, energy and environment, therefore, it would be an effective way to realize the sustainable development in China's iron and steel industry by strengthening the applications of HSLA steels continuously and positively.

Changes of Product Structure in China's Iron and Steel Industry

The history data on China steel production and consumption was given in Table 1. There was a tremendous growth in China crude steel production and consumption during the last decade. Figure 1 shows more clearly the growing trend of China iron and steel industry. As shown in Fig.1, the production and consumption of China crude steel are respectively 128 and 142 million tons in 2000, and the figures have increased to 822 and 773 million tons till 2013. However, there was an obvious change in China iron and steel industry in last year. 2014 China crude steel production is 822.7 million tons, and only 0.9% year-on-year growth rate, which is the lowest point compared with the past three decades. Moreover, the apparent consumption of China crude steel had started to fall in 2014, and there was about 3.4% decrease compared with the figure in 2013.

With the increase in crude steel production, the steel product structure in China had also a big change. As revealed in Table 1, in 2005, the total production of China crude steel was 305 million tons, incl. 233 million tons of carbon steel production which occupies 65.36% of total production, 103 million tons of low alloy steel which is 28.84% of total production, and 20.63 million tons of alloy steel (stainless steel included) which occupies the rest 5.80%. And till 2013, the total production of crude steel in China had increased to 822 million tons, and among these, the production of carbon steel was about 486 million tons and its ratio in total crude steel production decreased to 59.11%, and the production of low alloy steel reached to 275 million tons and the proportion increased to 33.51%, and alloy steel (stainless steel included) production was 60.63 million tons and occupied the rest 7.38%. Viewed the change of the history data on China steel product structure as shown in Fig.2, it can be seen clearly that the carbon steel occupied all the time dominant position in the whole China steel product structure before 2000 and the proportion can reach 70%-80%, while the proportion of low alloy steel (include C-Mn steel) is low than 15%; but during last decade, the proportion of the carbon steel has reduced to the level below 60%, while the proportion of the low alloy steel has a significant increase recently, and reaches to 33% till 2013.

Table 1 Changes of product structure in China's iron and steel products during 2005-2014 (million tons)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Crude Steel Production	355.79	421.02	489.71	512.34	577.07	638.74	701.97	731.04	822.00	822.70
Consumption	315.00	388.26	434.36	452.85	564.99	611.49	667.23	686.68	771.27	738.00
Non-alloy Steel	232.56	275.92	312.13	332.12	372.62	395.11	407.02	427.15	485.88	/
low-alloy steel	102.60	119.83	144.30	144.63	165.70	193.43	240.17	247.84	275.49	/
alloy steel	18.33	21.62	28.23	31.01	31.35	40.30	43.72	45.08	49.63	/
Stainless steel	2.30	3.65	5.05	4.58	7.40	9.91	11.06	10.97	11.00	/

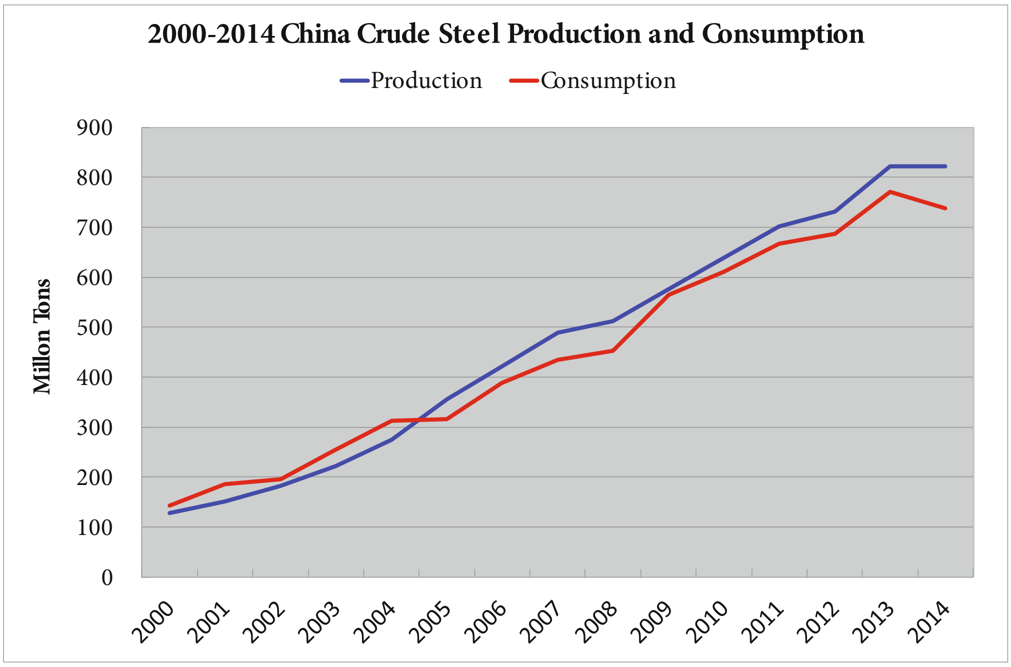


Fig.1 Production and consumption of China crude steel during 2000~2014

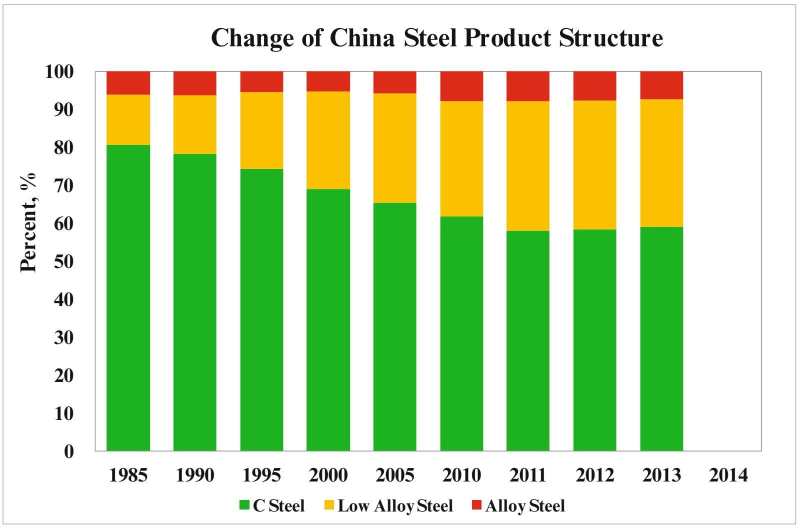


Fig.2 Changes of steel product structure in China

Fig.3 shows the outputs variation of China V and Nb microalloyed steels during 2001-2014. It can be seen from Fig.3 that there is a dramatic increase in the total microalloyed steel output in China in past 15 years, and the total V and Nb microalloyed steel output is only about 6 million tons in 2001, however, the output has increased to over 120 million tons in 2014 which is over 20 times of the output in 2001. It is worth noting that there is a fast growth in the production of China V microalloyed steel recent 5 years. The total V microalloyed steel output in China was about 22 million tons in 2009, while the output had reached to 88 million tons in 2014. The fast development of V microalloyed steel makes a great contribution to promote the production of China HSLA steel.

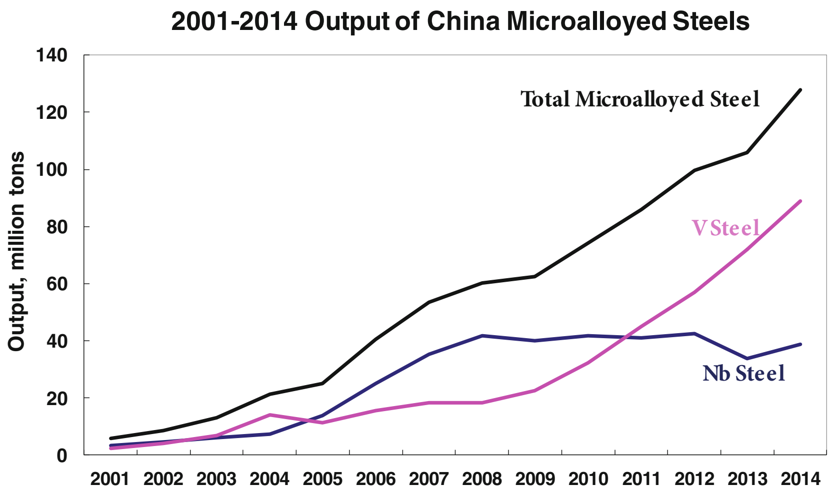


Fig.3 Outputs of V and Nb microalloyed steels in China

The changes of steel consumption in China main industries are shown in Table 2, and the evidence indicates that the consumption of construction steel occupies half more of the total consumption, and what following behind construction is the machinery, the consumption of which could reach 20% of the total consumption. With the fast growth in China automobile industry, the consumption of automobile steel continues to grow and the proportion increases to about 7%.

Table 2 Changes of steel consumption in China main industries, %

Year	Construction	Machinery	Light Industry	Automobile	Shipbuilding	Others
2001	59.0	15.6	12.7	4.1	1.3	7.3
2002	55.0	15.0	10.4	3.8	1.2	14.7
2003	52.4	15.1	9.1	4.7	1.1	17.3
2004	55.2	16.3	9.1	4.7	1.3	13.4
2005	52.4	15.9	8.2	4.8	1.3	17.5
2006	53.1	15.5	7.6	4.8	1.6	17.4
2007	/	/	/	/	/	/
2008	54.4	18.0	7.0	5.6	2.7	12.3
2009	57.7	16.5	5.4	7.9	3.5	9.0
2010	56.1	17.2	5.6	7.0	3.9	10.2
2011	54.8	18.0	5.8	6.6	3.5	11.3
2012	55.8	18.2	6.1	7.5	3.4	9.0
2013	56.0	18.5	6.2	7.9	2.3	9.1
2014	54.6	19.6	6.2	7.0	1.8	10.8
2015 (Prediction)	54.9	20.0	6.5	7.3	1.9	9.5

In fact, all China main industries, including construction, automobile, household electronics, shipbuilding, pipeline, bridge construction, container, machinery and high speed rail, etc., kept a rapid growth recently, and this had exactly a great contribution to the development and application of HSLA steel in China, as shown in Fig.4.

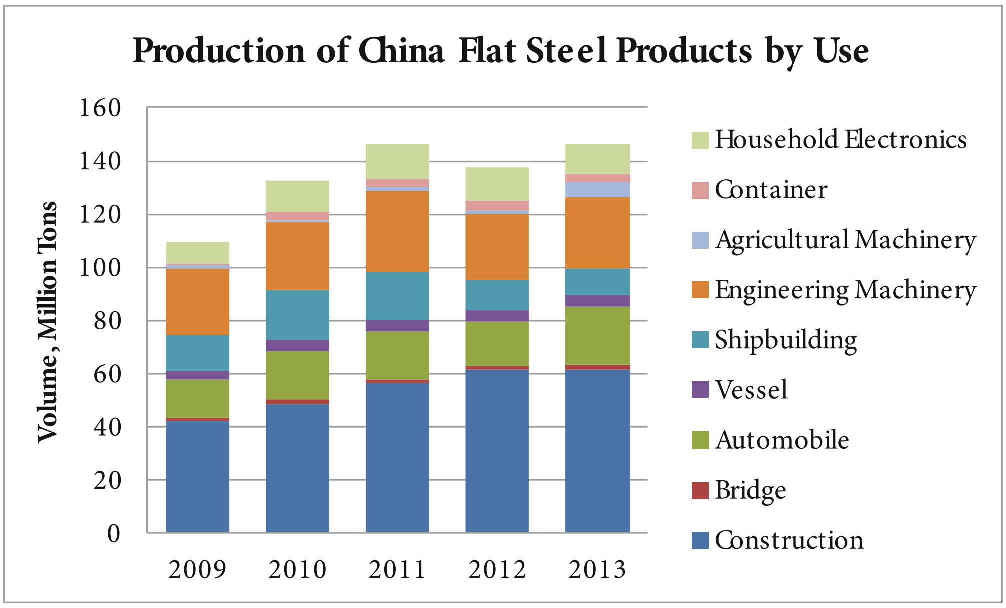


Fig.4 Production of flat products in China by use during 2009-2013

Latest Development of Physical Metallurgy in China

Microalloying Technology and TMCP Process

Enhanced-N in V steels promotes precipitation of fine V(C,N) particles, and improves markedly precipitation strengthening effectiveness of V(C,N), therefore, there is a significant saving of V addition in a given strength requirement. V-N microalloying can be also used effectively for ferrite grain refinement as well by the nucleation of intra-granular ferrite promoted by VN precipitates in Austenite in V-N steels. With the combination of the technology of intragranular ferrite (IGF) on VN particles and the recrystallization controlled rolling (RCR), a new controlled rolling technology has been developed in China and named as V(C,N) Precipitation Controlled Rolling Process (VCN-PCRP), as illustrated in Fig.5 which realizes ferrite grain refinement in V microalloyed steels. V-N microalloying process has been widely used for high strength rebars, section steels, forging steels, seamless pipes, and CSP strip steels in China.

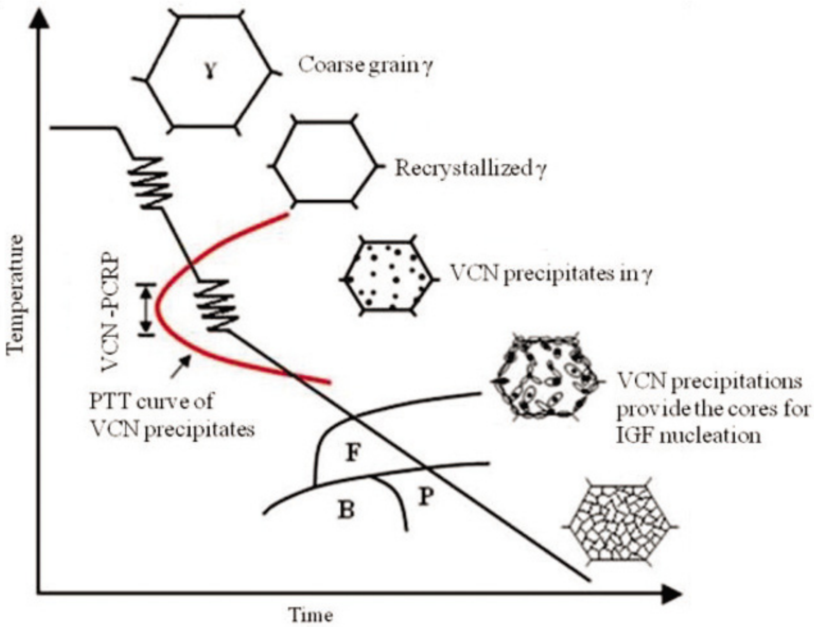


Fig.5 Schematic illustration of VCN-PCRP process

High Temperature rolling process (HTP) with the alloy design of high Nb had been successfully applied on the development of heavy X80 pipeline steel plate and strip with thickness of 18.4mm and 22.4mm which has been fully used for the construction of the west-east gas pipeline project. The experimental research results in Fig.6 indicate that austenite refinement, especially enough flattening after rolling process, plays an important role in controlling DWTT properties. In high Nb pipeline steels, the grain size of prior austenite can be refined into less than 20 μm during recrystallization rolling process. When the refined austenite is further flattened during the non-recrystallization process, the fine acicular ferrite can provide fine toughness and low DWTT. As for special heavy plates, fine low temperature toughness can also be obtained by refining the austenite in the middle of plate.

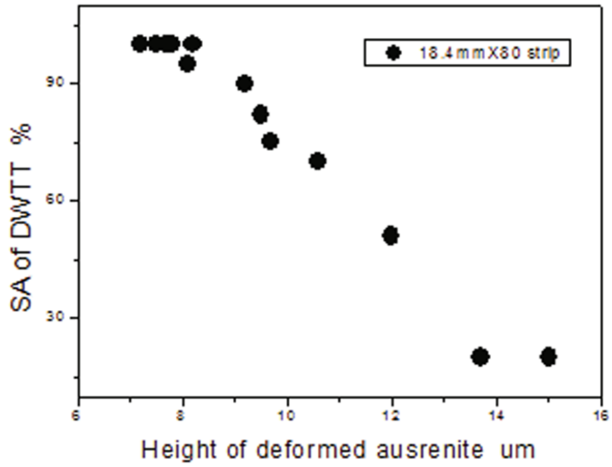


Fig.6 Effect of the pancaked austenite height on DWTT properties in pipeline steel

In order to solve the problems of low temperature rolling and addition of microalloyed elements in a traditional TMCP technology, the new generation TMCP (NG-TMCP) technology based on ultrafast cooling (UFC) has been developed in China. The core concept in NG-TMCP includes: 1) to achieve the strain accumulation in austenite during the continuous rolling at relatively high rolling temperatures; 2) ultra fast cooling after rolling to keep the work hardening of austenite; 3) to stop cooling temperature around transformation temperature; 4) to control the cooling route according to the requirements for microstructure and properties of steel, as shown in Fig.7. So far, this new technology has been widely used in China 31 hot rolling production lines for hot strip mill, plate mill, wire rod mill and applied to develop a series of high strength low alloy steel, automobile steel, pipeline steel, etc.

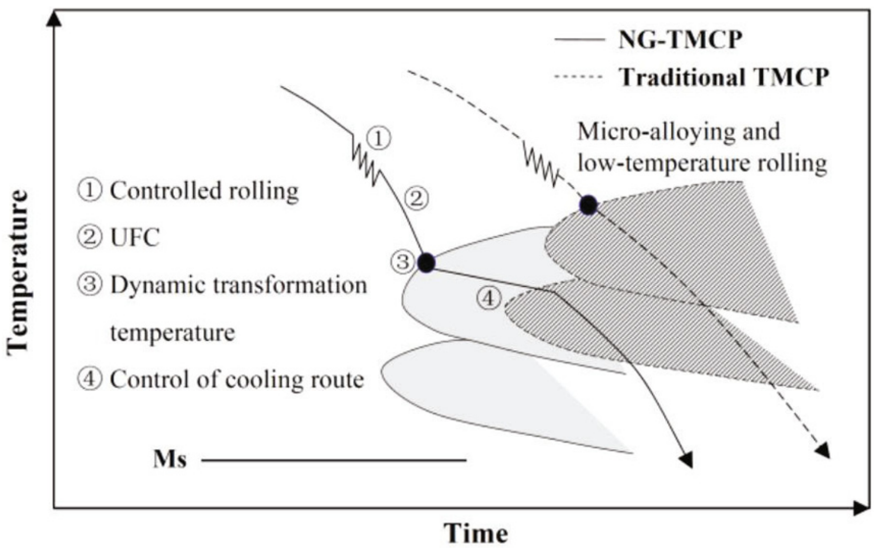


Fig.7 The comparison between NG TMCP and conventional TMCP

Advanced High Strength Steel Technology

Multi-microalloyed with V, Mo and Ti technology in low C Mn steel base was successfully used to develop 900 MPa ultra high strength ferritic steel. The multi addition of V, Ti and Mo in steel can not only increase the volume fraction of nano-scale MC particles, but also significantly inhibit MC particles coarsening, and thus the particle size could be refined remarkably. As shown in Fig.8, over half of MC particle sizes were less than 5 nm in diameter, and over 90% of the mass fraction of MC particles were less than 10 nm. As a result, more than 400 MPa increment of precipitation strengthening, almost twice than that of conventional microalloyed steel, was obtained with 0.5 wt% V-Ti-Mo microalloyed steel.

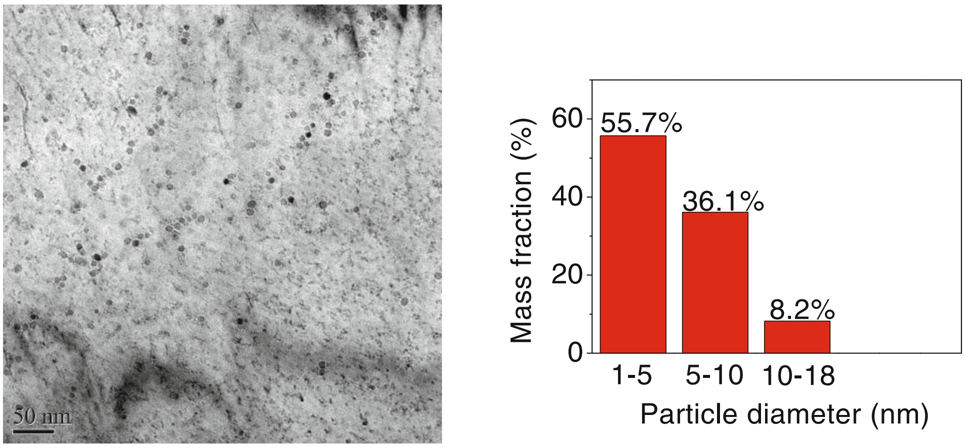


Fig.8 Nano-scaled (Ti,V,Mo)C precipitation and ferrite grain size in V-Ti-Mo microalloyed steel

Low carbon bainitic technology with the alloy design of Mn-Mo-Nb-V has been used in the development of X90-X120 grades pipeline steel in China. In 0.05%C-Mn-Mo-Nb-V X100 pipeline steel, the good combination of high strength and toughness can be guaranteed by fine bainitic microstructure with disperse M-A islands on the matrix in hot rolled plate products which have reached 725MPa yield strength and 350J of impact toughness at -20℃.

The alloy design of medium-Mn steels with different carbon contents processed by austenite reverted transformation (ART-annealing) fabricated the ultrafine duplex steels with large fractioned austenite which was given as one of the optimum structures to develop the third generation automobile steel with high strength and high ductility. The duplex structure with large fraction of austenite and ultrafine grain structure is capable of producing steels with excellent combination of strength and ductility, i.e., Rm×*A* about 30–50 GPa%, which is about two times of that of the conventional automobile steels and close to that of the TWIP steels, as shown in Fig.9. The experimental research results revealed that the ART-annealing of the medium-Mn steels would be at least one of the promising ways to fabricate the third generation automobile steels in the near future.

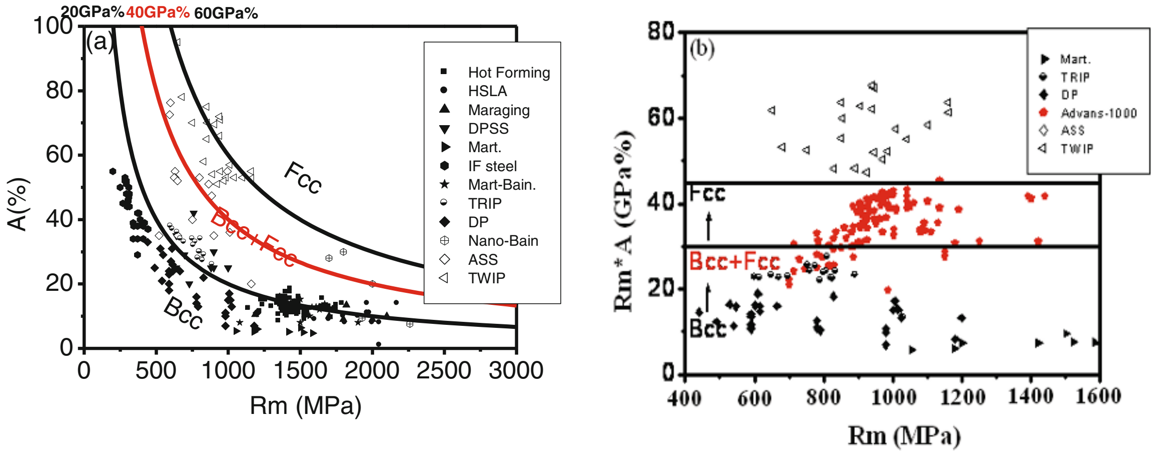


Fig.9 The development of 3rd generation automobile steel with alloy design of medium Mn

High Heat Input Welding Technology

Using Ti-Mg and Ti-Zr microalloyed technology, the size and distribution of Ti oxides can be effectively refined and altered, which can dramatically improve the CGHAZ toughness under the high heat input welding condition. As shown in Fig.10, when the heat input varies from 20 to 200 KJ/cm, the simulated CGHAZ toughness of Ti-Mg microalloyed experimental steel could be kept on a relatively high level, and that is mainly because the formation of intragranular ferrite promoted by oxides.

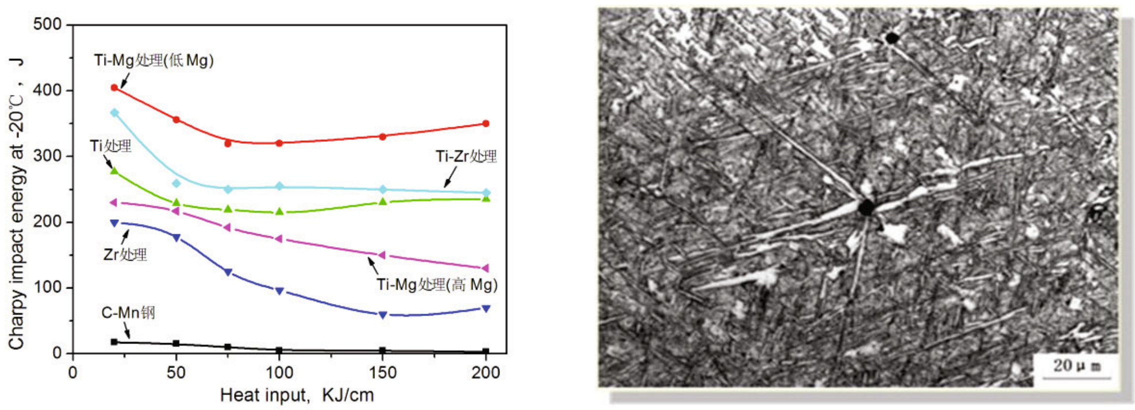


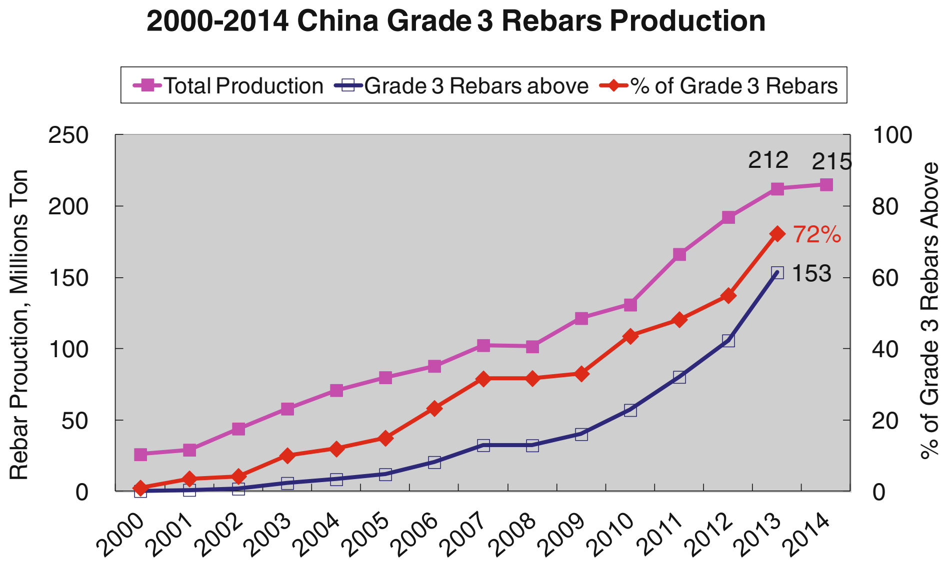
Fig.10 Effect of microalloying technology on simulated CGHAZ toughness

Development and Application of HSLA Steel Products in China

Construction Steels

More than half steel consumption in China is used in construction industry, and reinforcing bars, as the biggest steel products in China, take about one-fourth of the total steel production. Recently, there is a dramatic growth in production and consumption of hot-rolled rebars in

China as fast development of the national building industry, as shown in Fig.11, the total rebars production has reached to 215 million tons in 2014. It is specially worth to mention that there is also a significant change in China rebar product structure in past decade. As shown in Fig.11, the grade 2 rebar with yield strength 335MPa takes up 80% building market share 10 years ago, however, the proportion has been reversed right now, and the production of high strength rebar (Grade 3 over) has reached to 72% till 2013. The upgrade of building rebar has undoubtedly promoted the fast development and application of HSLA steels in China.



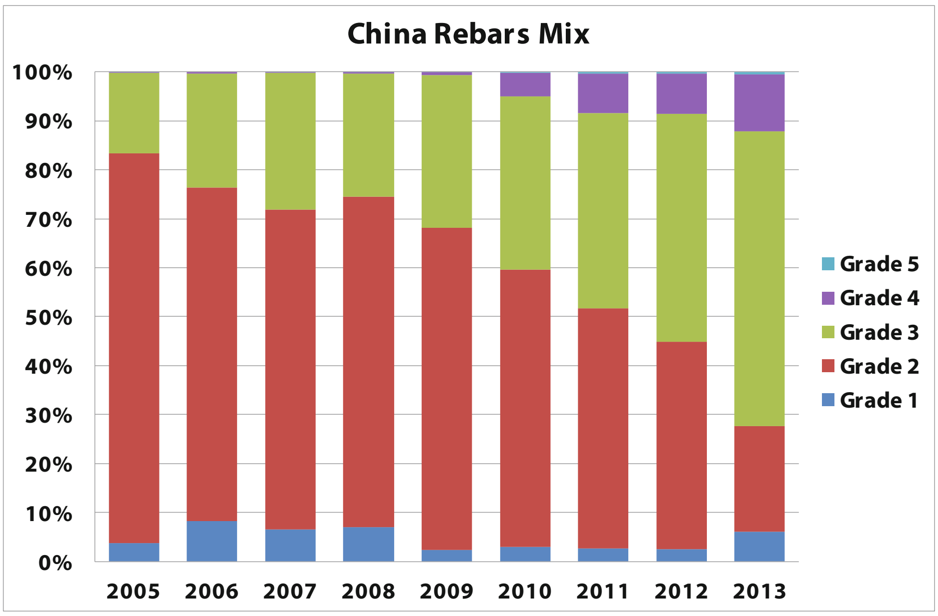


Fig.11 Changes of Production and products structure for China rebars steels last decade

Automobile steel

There is a very rapid growth in China automobile industry last decade, which contributed to the research, development and application of automobile steel in China. The latest statistical analysis shows the output of automobile reaches 23.72 million in 2104, and it promotes the production of automobile steels in China to reach to about 46.50 million in 2014, as seen in Fig.12.

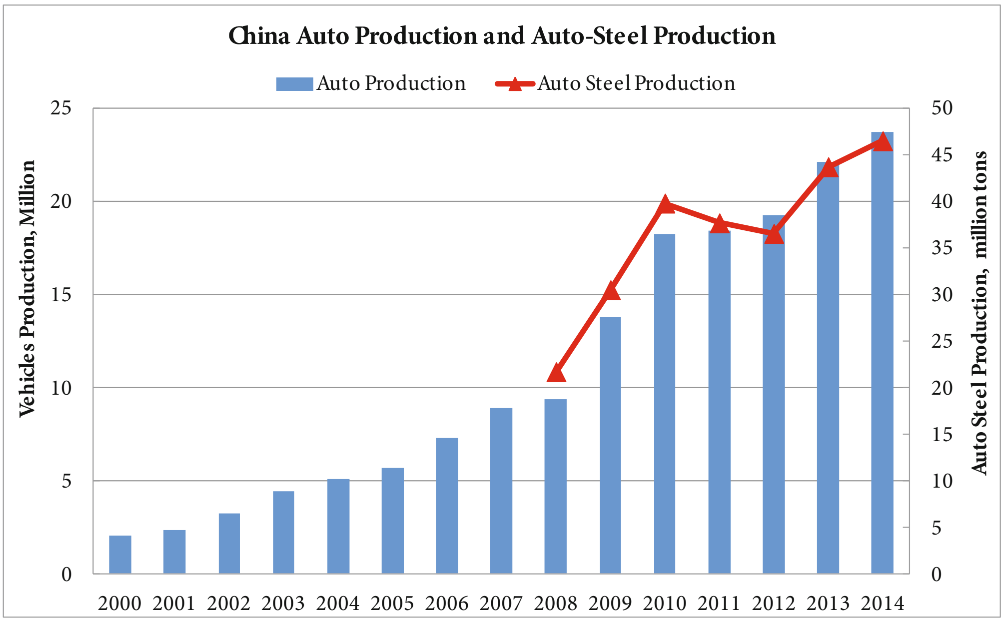


Fig.12 Changes in Vehicle production and automobile steel production in China

The changes of automobile steel products in China is far more than the rapidly growth of output. Today, a series of advanced high strength automobile steels (AHSS), incl. high strength IF steel, BH steel, DP steel and TRIP steel, etc., have been successfully developed and produced in most China automobile steel producers, and these AHSS products have also been widely used in China automobile industry. At present, the proportion of high strength automobile steel in China has reached 40% in 2014, and the application of coated steel in China automobile industry has increased to 45% in 2014, as shown in Fig.13.

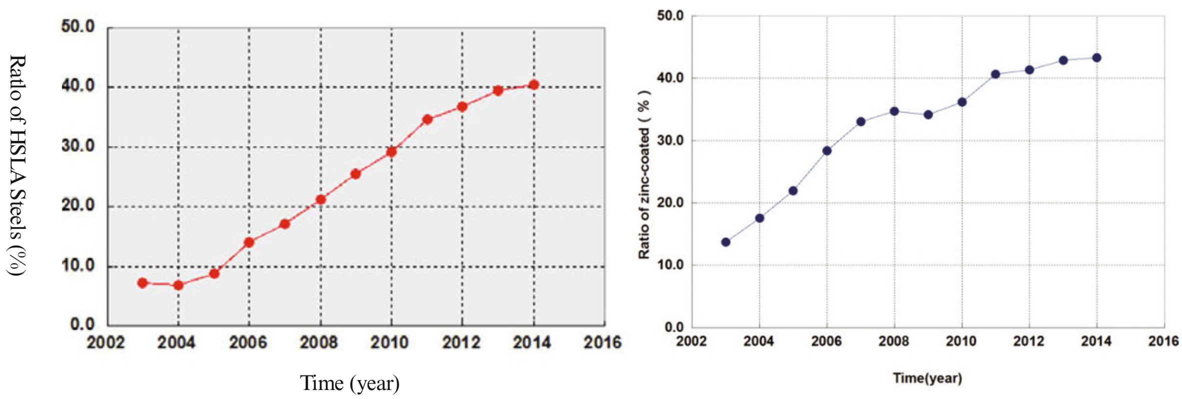


Fig.13 the proportion of high strength steel and coated steel in China automobile steel

Pipeline Steels

In recent years, the oil and natural gas pipelines are being constructed massively to meet the strong needs of rapid clean energy development in China, as shown in Fig.14. The development of long-distance transmission pipelines such as the 2nd and 3rd west-east natural gas pipelines and the China-Myanma pipeline have improved the level of manufacturing and construction of high grade pipeline steel in China. And two planned projects, i.e. the SINOPEC's synthetic natural gas (SNG) high pressure pipeline project and the China-Russia East large diameter X80 pipeline project will present new challenges on the development of pipeline steel.

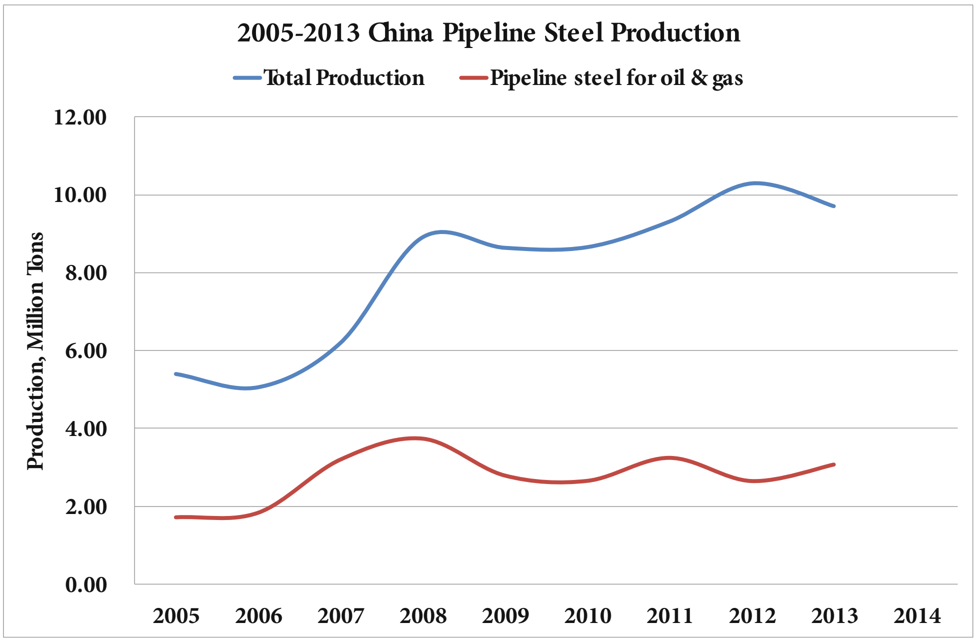


Fig.14 Change of China Pipeline Steel Production during last decade

The second and the third west-east gas pipeline projects are the longest in terms of single line among all high pressure X80 gas pipeline projects in the world. Both projects used spiral submerged arc welded (SSAW) pipe with 1219mm in diameter and 18.4mm in wall thickness for the first time, which was very difficult in techniques. Through in-depth studies on strengthening and toughening mechanisms of heavy gauge X80 plate/strip, the technical route that combines both high niobium microalloying and TMCP to realize microstructure refinement through the whole process was developed to produce X80 strip with 18.4mm in thickness and X80 plate with 22-33mm in thickness. The developed X80 steel pipe has excellent properties in strength, toughness and weldability.

X90/X100 ultra-high strength pipeline steel is now being developed in China in order to further improve the transmission efficiency and reduce the construction cost of pipeline, and great progress has been made in this aspect. In present, the CVN values at -10℃ of the trial-production ultra-high strength steel pipe can be stably controlled in the level of more than 280J, and the construction of a test section is now being planned in China. Furthermore, X80 strip of 21-22mm in thickness used in large diameter X80 SSAW pipes has been trial produced successfully, and will be applied in the China-Russia east pipeline project soon.

Important progress has also been made on the strain based design pipeline steel. The high deformable pipeline steels of X70 grade with 17.5-21mm in thickness and X80 grade with 26.4mm in thickness have been developed successfully and used in the China-Myanma pipeline and the third west-east pipeline projects.

As for the deep-sea pipeline steel, the developed X70 grade steel plate with 31.2mm in thickness has been applied in the China's first 1500m ultra-deep water pipeline project. Also, X70 grade ultra-deep water steel pipe with OD914×36.5mm has been trial-produced successfully under the support of national 863 project of China.

Shipbuilding and Offshore Steels

China's shipbuilding industry has entered into a new rapid growth in the new century. In 2014, the completion, new orders and handheld orders of China's shipbuilding accounted for 41.7%, 50.5%, 47.1% of the total world share respectively, and undoubtedly China is the No.1 shipbuilding country in the world. Fig.15 shows that the rapid development of China's shipbuilding industry promotes the production of shipbuilding plate steel in China significantly, and the production of China shipbuilding steel has reached a peak at 22 million tons in 2011, but unexpected global economic crisis causes a strong impact on China's shipbuilding industry, led to the subsequent decline of shipbuilding completion. It can been seen that 2013 production of China shipbuilding steel has descended to a low point with 11 million tons, only half level in 2011. Fortunately 2014 China shipbuilding steel production rebound to13 million tons, and seems to be some recovery in China shipbuilding industry.

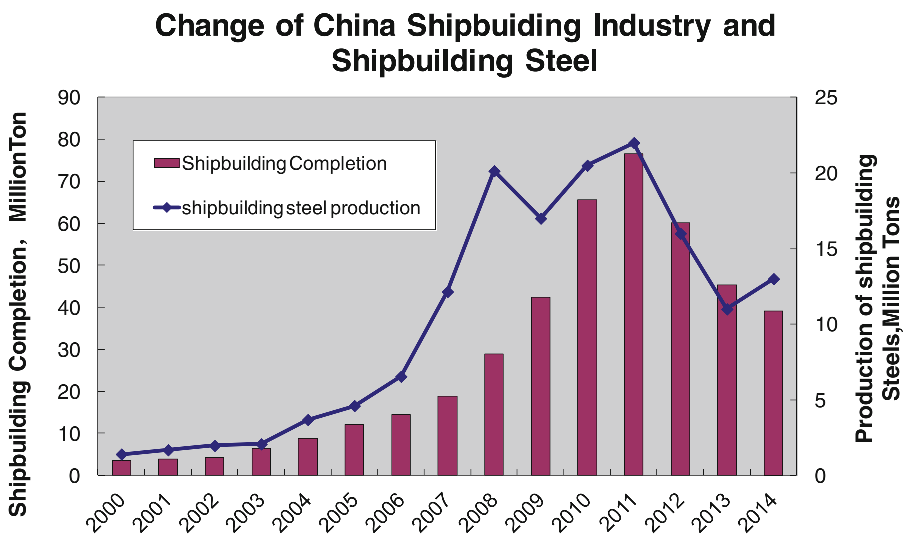


Fig.15 Development of shipbuilding industry and shipbuilding steels in China

In all of shipbuilding steel, high strength shipbuilding steel plate (32, 36 and 40kg) has become the main products in China's shipbuilding steels. In order to satisfy the development requirement of China shipbuilding and offshore engineering industry, a series of higher strength steels with 440MPa, 460MPa, 550MPa and 690MPa, etc., have been developed and applied in the actual engineering construction in China. At present, 178mm ultra heavy plate with 690 MPa for Jack-up platform has been developed in China. In order to meet the requirement of high efficiency on welding process, high strength shipbuilding plate with high heat input (~200KJ/cm) has also been successfully developed and applied in China. Recently, International Maritime Organization (IMO) approved Standard of corrosion resistant steel for COT of oil tank and it was enforced since January 1, 2014. R&D of the new anti-corrosion steel for the application of COT had been completed in China and the industrial anti-corrosion steel had been successfully used to fabricate a demonstration project of oil vessel with the max deadweight of 50,000 MT.

Conclusion

China's iron and steel industry is now facing the big pressure from over-capacity, shortage in resource and energy, and environmental protection. The development of HSLA steel is a cost-effective way to overcome these problems. In order to maintain the sustainable development of China's iron and steel industry, it will be the long-term task to promote the upgrade of steel products and adjust steel product structure in near future. The upgrade of China manufacturing industries offers a good opportunity for China steel industry to develop and promote the application of HSLA steels. It is the most important to expand the application of HSLA steel that is needed to strengthen the close cooperation in research, production and application in the whole industrial chains. In addition, there are very rich V and Ti resources in China, and it creates a good condition for us to promote the technical research, development and application of V and Ti microalloyed steel in China.