# Current Status of Advanced High Strength Steel for Auto-making and its Development in Baosteel

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**Abstract:** Along with the intensifying of energy crisis and environmental problems, energy saving and safety have become the most important issues for auto-making industry. To achieve these goals, weight reduction is most effective, which leads to the fast development and application of advanced high strength steels. In this article the lightweighting project of automobiles and its major achievement are introduced, with emphasis on the availability, application and characteristics of advanced high strength steel sheets (AHSS). The current status of the equipment for AHSS production is briefed, and the development of AHSS in Baosteel is also covered.

**Key Words:** automobile, lightweighting, AHSS

## 1 Introduction

Along with the intensifying of energy crisis and environmental problems, energy saving and safety have become the most important issues for auto-making industry. Among the many measures in reducing gas consumption and emission, reducing the weight is the most effective ---- 10% of weight reduction will lead to 3%～7% less of gasoline consumption[1~3]. To reduce the weight of the vehicle and thus energy consumption, the proportion of high strength steel used in auto-making is gradually increasing. To address this tendency, the investment of steel industry on the development and research of high strength steels also increases.

Conventional HSS are hardened by solid solution, precipitation or grain refining, while advanced high strength steels (AHSS) are hardened by phase transformation, and the microstructure may include Martensite, Bainite and retained Austenite. AHSS, including dual phase steel, TRIP steel, complex phase steel and martensite steel, are superior in strength

and ductility combination as compared with conventional HSS and thus facilitate the energy absorption during impact and ensure safety when reducing weight[4,5]. AHSS for auto-making include hot-rolled, cold-rolled and hot dip galvanized steel, which are all strengthened by phase transformation hardening though the processing parameters are somewhat different, as shown in Fig 1. Nowadays, a kind of hot stamped and die-quenched ultra high strength steel also has wide application in auto-making in Europe, which is trademarked as USIBOR1500 in Arcelor.

In this article, characteristics and the state of art of AHSS will be discussed in correlation with the lightweighting project and its achievements. The current status and future's prospect of advanced high strength steel for auto-making in Baosteel is also briefed.

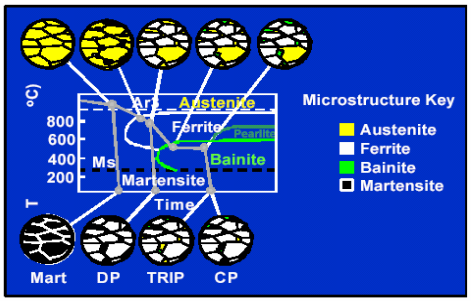


**Fig 1 Cooling Patterns and microstructure evolution in the production of AHSS**

## 2 Advanced High Strength Steels and Availability

The future's prospect of advanced high strength steels is bright though the present application is still limited. AHSS, which is strengthened by microstructure change during phase transformation, includes the following varieties:.

(1) Dual phase steel (DP)

DP steel is composed of ferrite and 5% to 20% of martensite, and the strength ranges from 500 ~ 1200MPa. DP steel, characterized by low yield ratio, high work hardening ratio, high BH value, no yielding and no room temperature ageing, is widely used in auto components that require high strength, good crashworthiness and good formability, such as wheel, bumper and other reinforcements. The basic composition of DP steel is C and Mn, and sometimes some Cr and Mo are added to enhance hardenability. DP steel is also called partial martensite steel when the martensite volume fraction exceeds 20% or more.

(2) TRIP steel

TRIP steel, with the microstructure of ferrite, bainite and 5%~15% retained austenite, contains hot rolled, cold rolled and hot dip galvanized products with strength ranging from 600~800MPa. TRIP steel is famous for high elongation and excellent sustainable work hardening ratio, and suitable for stretch forming. Si is the key element for the formation of retained austenite, but it is undesirable to make steel sheet with high surface quality.

(3) Complex phase steel (CP)

CP steel has similar microstructure with the TRIP steel except that CP steel has no retained austenite. With the hard phases like martensite and bainite and some help from precipitation hardening, the strength of CP steel ranges from 800 to 1000MPa, which makes the steel excellent for anti-crash rod, bumper and B pillar making.

(4) Martensite steel (M)

M steel is produced by fast quenching from austenite temperature to obtain lath martensite. M steel, no matter whether it is hot rolled, cold rolled and annealed or formed and post heat treated, is the highest in strength for auto-making and suits the needs of safety components such as anti-crash rod.

(5) MnB steel

MnB steel or hot-stamping and die-quenched steel contains mainly Mn and Boron, so it has excellent hardenability. Hot stamping process consists of heating blanks to austenization, then press formed while the blanks are still red hot and soft, and at last, the formed parts is quenched to hard phases like martensite within the die. The total processing time takes about 15 to 25 seconds.

Since the production of AHSS requires fast cooling, inadequate cooling capacity has to be compensated by adding more alloying elements. The addition of alloying elements deteriorates both the properties and increases environmental problem. Shown in Table 1 is the design of chemical compositions according to the different cooling capacity of continuous annealing lines. It is clear that fast quenching requires low alloy contents and thus is beneficial for both properties and environmental protection.

**Table 1. Effect of fast cooling capacity on the composition and processing parameters of DP steel**

| Grade | Typical composition for mist cooling （ACC） | Typical composition for Conventional cooling |
|---|---|---|
| 60Kg DP | 0.07C, 0.451Si, 1.85Mn | 0.10C, 0.4Si, 1.7Mn, 0.2Cr |
| 80Kg DP | 0.078C, 0.353Si, 1.74Mn, 0.019Nb | 0.16C, 0.4Si, 2.0Mn, 0.3Cr, 0.015Nb |

The processing parameters of AHSS production and the features of the products are shown in Table 2, and the design of compositions and product quality could be quite different on various processing lines.

Table 2 The processing parameters of AHSS production and the features of the products

| Products type | Processing parameters | Properties of steel |
|---|---|---|
| Hot rolled | Normal coiling (over 500℃) | High alloy content, low weldability |
| | Low temperature coiling(lower than 300℃) | Low alloy content, good mechanical property, excellent weldability |
| Continuous annealed | HGJC: max cooling speed 50℃/s | High alloy content |
| | $H_2$－HGJC: max cooling speed up to more than 100℃/s | Relatively low alloy content，good weldability |
| | RQ: max cooling speed 100℃/s | high alloy content，low weldability， some problems with the profile of the steel sheet |
| | ACC: max cooling speed 200℃/s | Low alloy content, good mechanical property, excellent weldability |
| | WQ: max cooling speed 2000℃/s | Lowest alloy content, good mechanical property, excellent weldability |
| Hot dip galvanized DP | HGJC: max cooling speed 50℃/s | High alloy content, good corrosion resistance |

Though the wide application of AHSS in auto-making has long way to go, giant steel suppliers like Thyssen－Krupp, NSC and JFE have made sufficient preparation. Shown in Table 3 is the availability of AHSS worldwide.

**Table 3 The availability of AHSS worldwide early the 21st century**

| | Tensile strength /MPa | Availability (Hot rolled) | Availability (Cold rolled) | Availability (Hot dip galvanized) |
|---|---|---|---|---|
| DP | 400 | | * | |
| | 450 | * | *** | ** |
| | 500 | * | *** | *** |
| | 550 | *** | *** | ** |
| | 600 | *** | *** | *** |
| | 700 | ** | *** | *** |
| | 800 | *** | *** | ** |
| | 900 | | * | * |
| | 1000 | | *** | under development |

| | | | | |
|---|---|---|---|---|
| | 1200~1400$^{+}$ | | ** | under development |
| CP | 800 | * | | |
| | 900 | * | | |
| | 1000 | * | under development | |
| | 1200~1400$^{+}$ | | under development | |
| TRIP | 600 | * | ** | under development |
| | 700 | ** | under development | * |
| | 800 | ** | * | under development |
| | 900 | | under development | |
| | 1000 | | * | |
| M | 600 | | * | under development |
| | 700 | | | * |
| | 800 | | | under development |
| | 900 | under development | | |
| | 1000 | | * | |
| | 1200~1400$^{+}$ | ** | *** | |

*** Widely available ** Restricted available * Limited available

## 3 The Future Prospect of the application of HSS and AHSS

The light weighting project is the response of steel producers to the challenge of Aluminium and other non-ferrous substitutes in the future to maintain steel's major role in automotive industry. The project includes ULSAB, ULSAC and ULSAS as well as the ULSAB—AVC, which comprises conceptual designs for two vehicles, a 2-door hatchback and a 4-door, mid-size sedan. A consortium of 33 world's leading steel producers attended and funded the ULSAB-AVC study. Baosteel is the only steel supplier from mainland China who takes part in the project.

ULSAB and ULSAC are noteworthy because of the large amount of high strength steels utilized in the project and the consequent weight reduction. ULSAB and ULSAC achieve 25% and 32% of weight reduction respectively. Meanwhile the cost is 30% lower than that of aluminium built auto body. The ULSAB—AVC meets the five-star impact standard and the cost is as low as to be affordable by common households. Shown in Table 4 is the application of various high strength steels in ULSAB—AVC.

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**Table 4 Summarization of the variety and percentage of high strength steels utilized in ULSAB—AVC**

| | C class | | | PNGV class | |
|---|---|---|---|---|---|
| Body structure | grade | Weight/kg | Proportion/% | Weight/kg | Proportion/% |
| | HSLA350/450 | 2.68 | 1.33 | 2.68 | 1.23 |
| | IF 300/420 | 5.77 | 2.86 | 4.18 | 9.11 |
| | BH 210/340 | 6.64 | 3.29 | 8.69 | 3.98 |
| | BH 260/370 | 16.77 | 8.31 | 12.69 | 5.82 |
| | DP 280/600 | 7.84 | 3.89 | 15.02 | 6.89 |
| | DP 300/500 | 18.14 | 8.99 | 17.4 | 7.98 |
| | DP 350/600 | 6.58 | 3.26 | 6.02 | 2.76 |
| | DP 400/700 | 9.14 | 4.53 | 9.14 | 4.19 |
| | DP 500/800 | 47.71 | 23.64 | 49.21 | 22.56 |
| | DP700/1000 | 59.32 | 29.40 | 65.47 | 30.02 |
| | Trip 450/800 | 8.44 | 4.18 | 8.92 | 4.09 |
| | CP 700/800 | 1.13 | 0.56 | 1.13 | 0.52 |
| | Mart 950/1200 | 6.09 | 3.02 | 5.83 | 2.61 |
| | Mart1250/1520 | 1.77 | 0.88 | 1.77 | 0.81 |
| Closure | IF 260/410 | 2.52 | 6 | 5.72 | 10 |
| | DP 350/600 | 18.17 | 46 | 26.92 | 45 |
| | DP 500/800 | 5.31 | 13 | 7.22 | 12 |

From Table 4 we can see that the application of AHSS strengthened by phase transformation hardening exceeds 80% and AHSS become the major part of materials for auto body structure. Among these AHSS, DP steels, especially those of 800 and 1000MPa grades account for the largest portion. Because the lightweighting project directs to the market demands in the future, we believe that only a steel producer who can make AHSS up to 1000MPa grade is well prepared for the future's market demand.

## 4 The current status and future prospect of steel sheet for auto-making in Baosteel

Steel for auto-making is one of the key products of Baosteel, and Baosteel has consistently endeavored to provide more new products with better quality for auto-makers.

Through years' effort, Baosteel has built three continuous annealing lines with roll quenching (RQ) or high speed gas jet cooling (HGJC), as

well as four hot dip galvanizing lines for auto panel production. As for the products, Baosteel has developed high strength IF steel, BH steel and isotropic steel which won successful application in many car models.

As the market competition of auto steel intensifies, to ensure sustainable development, Baosteel has focused on the development of AHSS in the future, which includes:

(1) the development of new high strength and ultra high strength AHSS including DP, TRIP and CP.

(2) the study on the application technology of AHSS, including the forming, high speed dynamic property study, fatigue and weldability study of these products to set a firm foundation for the smooth application.

Up to now, Baosteel has achieved primary success in the development and production of hot rolled DP and TRIP steel. For cold rolled and HDG AHSS, DP steels of grades up to 800MPa are commercially available, and Baosteel has also developed 600MPa TRIP and 500MPa DP and achieved successful trial production. Furthermore, research aimed at improving the weldability of the DP steels to satisfy the demands of some special customers is also underway, and research on hot dip galvanized TRIP steel is also launched.

A new processing line aiming at solving the technological problems in AHSS production is just under consideration. In the near future Baosteel will be able to provide most of the AHSS products and meet the future's demand of the market.

## 5 Concluding remarks

The achievements of the lightweighting project indicate that massive usage of AHSS is the only way to defend the market of steel as the first choice for auto making. Major steelmakers in the world who are advanced in equipment and technologies have accumulated enough knowledge and experience in the production and application technology of AHSS.

To improve the technology of producing AHSS and build up its advantage

in market competition, Baosteel has consistently devoted to the technical innovation, equipment renewal and project development. AHSS will be one of the most important directions in our next stage of development.

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