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High Strength Steel Sheets for Light Weignt Vehicle

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Abstract

Automobiles and steel sheets are bound together by a strong link between supply and demand. Steel has progressed by corresponding to automotive needs. In recent years, there is a heavy demand for lightweight automobiles to correspond to the global environment and a high strength steel sheet as a material that can be both lightweight and improve the performance of safety in impacts that are gathering attention. Currently, the share of high strength steel sheets is approximately 30% of white body weight. Along with reorganizing the meaning of strengthening steel sheets for use in automobiles, this paper discusses the characteristics and examples of the application of the main strengthened steel sheets from among the high strength steel sheets that were developed to meet these performance requirements, despite the fact that the performances required of the steel sheets that are used in each of the parts that compose an automobile are different.

1. Preface

Annual production of four wheeled vehicles in the Japanese automobile industry was less than 1 million units in 1960 but it grew rapidly to reach 5 million in 1970 and surpassed 13.5 million in 1990. Domestic car production decreased thereafter, but the production of Japanese car builders by their overseas plants increased steadily and their total production was 15.5 million per annum as of 1995.[1)] When we look at cars from the raw materials viewpoint, an automobile is composed roughly of 70% of steel (55% plain carbon steels, 15% special steels), 6% of aluminum and 7% of plastics in the average as of 1992. Thus, steel is by far the dominant material for the car industry and the main steel products for cars are low carbon steel sheets. The car industry consumed in 1995 a total of more than 10 million tons of hot and cold rolled steel sheets including surface treated sheets[2)].

Since cars and steel sheets are closely tied to each other, the remarkable growth Japan's steel sheet production showed during these years both in quantity and quality was largely a result of the efforts Japanese steel industry exercised in responding to the requirements of the car industry. After briefly reviewing the history of the car industry's requirements and the developments of steel sheet products in response to them, this report will focus on high strength steel sheets developed for making car bodies lighter for energy conservation.

2. Improvements of Steel Sheets Responding to Needs from Cars

The mass production of cars and large size forming processes introduced to Japan around 1955 required quantitative increases and qualitative enhancement of steel sheets. Wrinkles and cracks of the sheets were then the most important factors in the press forming and hence the improvement in deep-drawing properties of Al-killed steels was regarded as essential. Imported Al-killed steel sheets were used during those days for deep-drawing parts, but appropriate production conditions and technology were quickly established in Japan and domestic steel sheets supported growth of the Japanese car industry during the 1960's. As the car production grew during the decade, shape fixability began to be regarded as essential for the enhancing shape quality of car body panels, which fact resulted in demands for low yield strength steels. The open coil annealing process introduced from USA made crystal grain growth possible by means

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of decarburization and denitrification as well as suppress of aging and low yield strength by means of reducing solid solution of carbon and nitrogen.

During the second half of 1960's demands for cars grew dramatically in Japan and, as continuous and high speed forming techniques expanded their applications, the number of car models increased and model changes became more frequent. This, in turn, raised demands for sheets having stable formability and those that could be used at times of fabrication line troubles at the car builders' plants. In parallel to the above, Japanese steelmakers rapidly improved their high purity steel production capacity by the use of vacuum degassing and continuous annealing technology, and interstitial free (IF) steels having very good deep-drawing performance such as Ti-stabilized ultra low carbon steels were developed.

The social aspects of cars began to be considered in 1970's and safety standards against collision were instituted in various countries, triggered by the Experimental Safety Vehicle proposed by Department of Transportation in the United States. Consideration of the social aspects changed the attitudes of carmakers from soft, formable materials to hard ones. However, because the hard materials were then meant only for strengthening structural members of comparatively low forming intensity such as bumpers and reinforcements, the steelmakers could cope with the new trends by application of existing high strength steel technologies for shipbuilding and line pipe materials.

After the first oil crisis in 1973, however, the requirements for fuel economy, clean exhaust gas and reduction of CO_2 emission became more manifest and the reduction of vehicle weight began to be pursued as a countermeasure. The main approach for lighter car bodies was to make the thickness of structural members smaller using higher strength steel materials, thus maintaining the structural strength of the bodies. As the objective at this stage was to make the entire body lighter using higher strength steels, parts requiring intensive forming work such as internal and external body panels and undercarriage parts (all of which were also responsible for a considerable proportion of the body weight) had to be additionally considered for the weight reduction. High strength steels having good formability were required for this purpose.

Steel sheets for such applications have to be capable of being formed by existing press forming methods besides having high strength. Steel sheets having 340 MPa tensile strength or more are called "high strength" steel sheets because 340 MPa is a tough value for press engineers. Newly developed "high strength" and high formability thin steel sheet products include P-added sheets, bake-hardening (BH) steel sheets, dual phase (DP) steel sheets, heat treatment hardening steel sheets, retained austenite (Transformation Induced Plasticity - TRIP) steel sheets, etc. High strength steel sheets are presently contributing significantly to reducing the weight of car bodies, responsible for approximately 30 % of the white body weight[3].

3. Significance of Raising the Strength of Steel Sheets for Cars

As shown in **Table 1**, a white body is composed of panels, structural members, undercarriage parts and reinforcements. Some specific properties are required of these components depending on their functions: formability, panel stiffness, dent resistance and corrosion resistance are important especially for the panels; formability, stiffness, crashworthiness, fatigue resistance, corrosion resistance and weldability for the structural members; formability, stiffness, fatigue resistance, corrosion resistance and weldability for the undercarriage parts; crashworthiness and weldability for the reinforcements.

Table 1 Kind of car body components, typical parts, required properties and pricipal factors for thickness selection

Kind of components	Typical parts	Required properties	Principal factors for thickness selection
Body panels	External: Door Internal: Floor	Formability (deep drawability, stretchability, shape fixability), panel stiffness, dent resistance, corrosion resistance	Panel stiffness, Dent resistance
Structural members	Members Cowl box	Formability (stretchability, bendability, shape fixability), structural rigidity, crashworthiness, fatigue strength, corrosion resistance, weldability	Structural rigidity, Crashworthiness, Fatigue strength
Undercarriage parts	Lower arm Wheel	Formability (stretchability, stretch flanging, shape fixability), structural rigidity, fatigue strength, corrosion resistance, weldability	Structural rigidity, Fatigue strength
Reinforcements	Door impact beam	Formability (bendability, shape fixability), crashworthiness, weldability	Crashworthiness

Thickness of the panels is decided to satisfy panel stiffness and dent resistance. Because the dent resistance[4] enhances as yield strength of the formed parts increases, high strength materials allow for smaller thickness and makes the parts lighter, provided that formability and stiffness are maintained. Likewise, because the crashworthiness[5] and fatigue strength[6] become higher as the material strength increases, high strength steels can bring about lighter body weight and enhanced collision safety, provided that structural rigidity is maintained. The situation is similar with regards to the under-

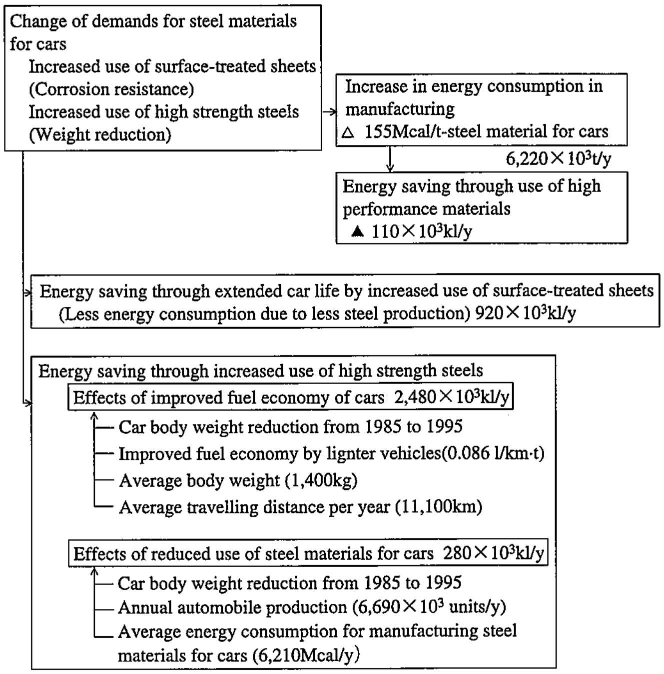

Fig.1 Schematic diagram of energy saving mechanism through use of high performance steel sheets[7]

carriage parts and the reinforcements because crashworthiness and fatigue strength increase together with the material strength, and thus the use of high strength steels brings about significant advantages.

Energy saving effects by wider use of high strength steel sheets have been tentatively estimated by the Ministry of International Trade & Industry and the Japan Iron and Steel Federation. **Fig.1**7) is a schematic diagram of an energy saving mechanism through the use of high performance steel sheets with high strength and surface treatment. It tells that an amount of energy equivalent to 3.57 million kilo liters of heavy oil per year will be saved in all of Japan when the average life of cars is extended from 6.7 to 9.3 years by the use of surface-treated sheets and the percentage of high strength steel sheets for white body is raised from 10% to 30%. The suggested energy saving equals to several percents of the energy consumption of the entire steel industry of Japan.

4. Principal High Strength Steel Sheet Products and the Strengthening Mechanisms

Fig.28) shows strengthening mechanisms and relation between the achieved strength level and the formability indices of hot rolled high strength sheet products so far developed and **Fig.3**9) the same of the cold rolled products. Principal high strength sheet products and their strengthening mechanisms are described hereafter.

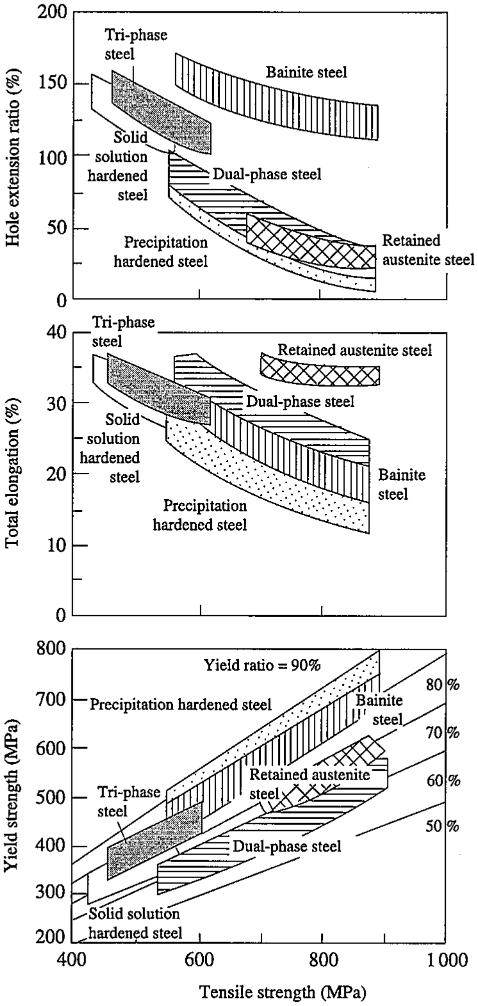

Fig.2 Relation between tensile strength and formability of hot rolled high strength steel sheets8)

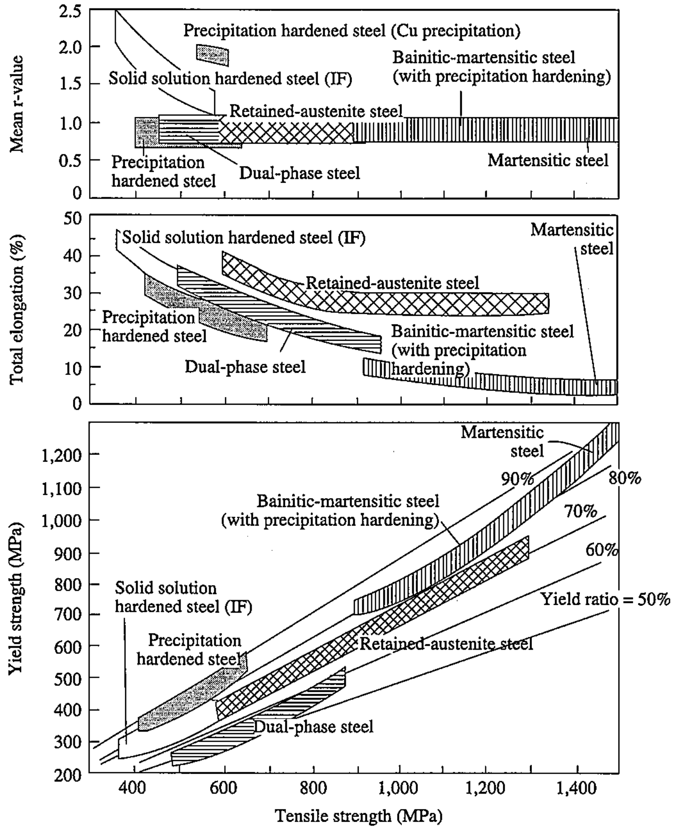

Fig.3 Relation between tensile strength and formability of cold rolled high strength steel sheets9)

4.1 Solid Solution Hardened High Strength Steel Sheets

Essential characteristics of high strength steel sheets for external body panels are high r-value and low yield strength. Low yield strength is required because it has been empirically known that, for preventing surface deflection from taking place during press forming, yield strength has to be 240 MPa or less8). It is a normal practice for obtaining high strength to add C, Si, Mn, P, etc. for the purpose of making ferrite matrix harder, but P is normally used for deep-drawing quality sheets since the other elements lower r-value when there is solid solution carbon10). Low carbon Al-killed steel sheets with P has a high r-value (approximately 1.6) and is widely used. When it is used for external body panels its strength grade (defined by tensile strength in Japan) is now regulated to be less than 340 MPa for keeping its yield strength at 240 MPa or less.

A steel sheet product having yet better deep-drawing formability than the rephosphorized low carbon Al-killed steel can be manufactured by adding solid solution hardening elements such as P, Mn, Si, etc. to IF steels11, 12). As this product does not have any solid solution carbon or nitrogen it is basically non-aging. When there is no solid solution carbon, embrittlement tends to happen at secondary working, and a small amount of B is sometimes added for avoiding this13).

4.2 BH Sheets and Heat Treatment Hardening Steel Sheets

BH sheet product is soft at forming works but hardens during baking paint finishing (held at 170°C for about 20 min). A suitable amount of solid solution carbon is left in the steel and it anchors dislocations introduced by press forming work by the baking and this process raises yield strength. As the amount of bake-hardening depends on the amount of strain imposed by the forming work and is

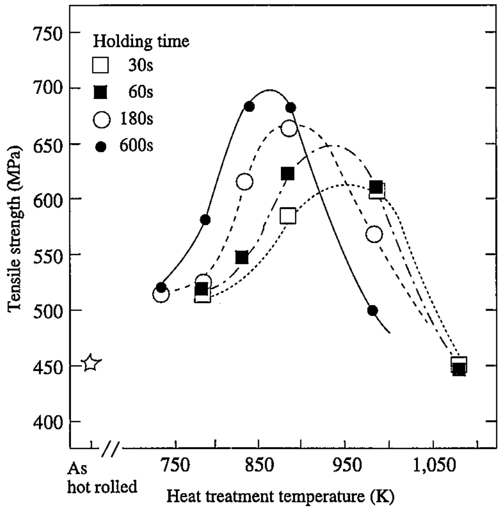

Fig. 4 Effects of heat treatment temperature and holding time on tensile strength of hot rolled steel sheets with 1.6 mass% of Cu addition[14]

large in the low strain ranges, BH sheets are suitable for comparatively low forming applications such as door and hood. Since the bake-hardening effect takes advantage of strain aging by solid solution carbon, it is important to avoid material deterioration through aging at room temperature for keeping the bake-hardening amount. For controlling recovery of yield elongation during storage at room temperature, the BH amount is restricted not to surpass 60 MPa. Though this product was initially developed based on box-annealed low carbon Al-killed steel, it is now manufactured mainly based on continuously annealed ultra low carbon steel, which has a very good formability.

There have been developed new steel sheet products whose tensile strength as well as yield strength increases by 150 - 250 MPa when it is heat-treated at 500 - 700°C for a few minutes after press forming[14]. Thanks to the addition of more than 1 mass % of Cu to IF steel, these products are as formable as 390 MPa class IF steel before heat treatment but they develop a 590 MPa class strength after the treatment. **Fig.4**[14] shows examples of strength increase by heat treatment in the case of 1.6 mass % Cu-added steel. Tensile strength goes up by 230 MPa when the material is held at 550°C for 10 minutes. This significant strengthening is brought about by precipitation of bcc-Cu in a meta-stable phase several nm large and in coherency with the ferrite matrix[15]. When cold rolled and annealed under the appropriate conditions, this steel will show a 590 MPa class tensile strength and high r-value (approximately 1.9) due to a formation of a re-crystallization texture, which presents good deep-drawing properties[16].

4.3 Microstructure Hardened High Strength Sheets

Microstructure hardened steels utilize low temperature transformation phases and their mechanical properties change in a wide range depending on the phase composition of microstructure. Strength can range as widely as from 440 to 1,470 MPa.

4.3.1 DP Steel and Bainite Steel Sheets

Dual phase steel sheet shows lower yield strength compared with other types of steel having the same tensile strength because of mobile dislocations existing in the vicinity of the boundary of ferritic and martensitic phases, and thus presents low yield ratios. For this reason, its elastic recovery after forming work is small and shape fixability is good. As it also shows larger elongation than precipitation hardened steel sheets and superior stretchability and fatigue resistance[17], it is used for wheel discs and the like. But, its stretch flangeability, which is dependent on local deformation capacity, is comparatively low. This is suspected to be because the boundary of the two phases of different ductility initiates ductile fracture. Besides, the r-value of cold rolled DP sheets is low presumably due to existence of martensite, which does not contribute to raising r-value in terms of crystal orientation. Another suspected reason for the low r-value is that multiple slipping occurs during plastic deformation around the hard martensite structure causing random deformation.

Hot rolled sheets mainly composed of bainite have strength ranging from 440 to 880 MPa and they characterize in good stretch flangeability by virtue of a homogeneous microstructure. Based on this a new product, having yet better stretch flangeability has been developed through dispersion of small cementite by means of improvements in chemical composition and rolling conditions[18]. This product is suitable for parts requiring severe burring workability such as suspension links.

4.3.2 TRIP Steel Sheets

This extremely ductile sheet product taking advantage of transformation-induced plasticity was initially developed as a highly stretch-formable sheet product. It has meta-stable austenite transformable into martensite contained up to 30% in bainite or ferrite + bainite matrix[19]. Though TRIP steels were conventionally manufactured as high alloy steels, commercial TRIP sheets of today have simple C-Si-Mn series chemical compositions. The simpler chemical compositions were made viable by stabilizing the austenite phase through distribution of alloy elements in the two phase region and concentration of carbon into austenite during bainite transformation.

This product has a good deep-drawability besides a high n-value and an excellent stretch-formability. It is generally understood that deep-drawability of steel sheets depends on the r-value. The reason the TRIP sheet product has a good deep-drawability despite its low r-value because of its random texture is that the way austenite transforms into martensite under forming work changes depending on type of deformation. As shown in **Fig.5**[20] it is difficult for retained austenite to transform into martensite in the shrink flanging deformation portions and thus deformation resistance is kept low, but the above transformation is easy to take place in the tensile deformation portions and thus tensile strength becomes high. A stress condition favorable for deep-drawing work (low shrink flanging resistance and

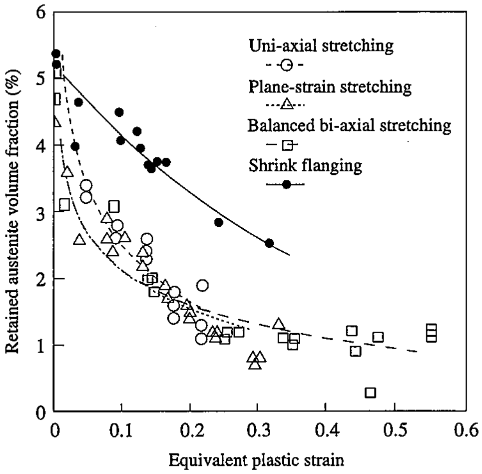

Fig.5 Effect of deformation modes on reduction of retained austenite in TRIP steel[20]

high tensile strength) is given to it in this fashion.

4.3.3 Ultra High Strength Sheets

Ultra high strength sheet products of 980 - 1,470 MPa strengths taking advantage of bainite or tempered martensite are being developed[21]. Since reinforcing parts such as bumper reinforcements are formed by bending work, materials have to have good bend-formability besides high strength. Bend-formability of ultra-high strength sheet products is closely related with homogeneity of microstructure[21]. This is because cracks under bending work are believed to originate from boundary between soft and hard phases or within hard phase. Delayed fracture caused by hydrogen has also to be considered with regards to the ultra high strength materials over 980 MPa. It is necessary to control hydrogen trap site for avoiding delayed fracture and the control of carbides and retained austenite[22] is being practiced for the purpose. Recently 980 - 1,180 MPa class ultra high strength sheets are used for bumper reinforcements for the purposes of weight reduction and good maneuverability of the vehicles.

5. Conclusion

In order to further increase the share of high strength steel sheets in the car material composition it is necessary to pursue further technical improvements both in material manufacturing and utilization. Fields of steel sheet utilization for cars include forming, welding, joining, painting and corrosion protection. R&D efforts of Japanese steelmakers in these fields are characterized in that higher reliability of the steel materials has been pursued and achieved through development of evaluation methods using car components of real sizes and shapes, in addition to fundamental researches and tests using test pieces. It is becoming more and more increasingly important for steelmakers, in addition to the above, to add values for the customers by becoming capable of proposing the best method of application of each of the products.

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