Advanced Materials for Automotive Application

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Abstract. In this paper some recent material developments will be overviewed mainly from the point of view of automotive industry. In car industry, metal forming is one of the most important manufacturing processes imposing severe restrictions on materials; these are often contradictory requirements, e.g. high strength simultaneously with good formability, etc. Due to these challenges and the ever increasing demand new material classes have been developed; however, the more and more wide application of high strength materials meeting the requirements stated by the mass reduction lead to increasing difficulties concerning the formability which requires significant technological developments as well. In this paper, the recent materials developments will be overviewed from the point of view of the automotive industry.

1. Introduction

There is an extremely strong competition in car manufacturing leading to larger model variety, and shorter model cycles. The increased competition also leads to a very intense development activity to increase productivity and to reduce costs, as well as to meet customers' demand and increased legal requirements. Application of lightweight design principles is one of the most important trends to meet the above requirements. Obviously, the new design concepts require new materials.

As sheet metal forming is one of the most important manufacturing processes in the automotive industry and at the same time very sensitive for material properties, application of new material grades requires great attention both from designers and forming technologist engineers. In this paper, the material developments in the automotive industry will be overlooked first of all from the point of view of sheet metal forming.

2. Material development tendencies in sheet metal forming with special respect on automobiles

In recent years, the reduction of fuel consumption together with the increasing comfort and legal requirements led to the intensive development of innovative new materials. Enhanced stiffness together with weight reduction resulted in the development and wide application of various grades of high strength steels. Nowadays, several micro-alloyed and phosphorous-alloyed steels both with and without bake-hardening are frequently used. An increasing use of interstitial-free (IF) steels, dual-phase and TRIP-steels, as well as the ultra-low and super ultra-low carbon steels can also be observed.

These developments in steel materials are shown in Figure 1. concerning the last 35-40 years. From this figure, it can be seen that from the elaboration of various micro-alloyed steels in the mid-seventieth of the last century, there is a continuous pressure on material development leading to the appearance of new advanced steel materials practically in each five year [2].

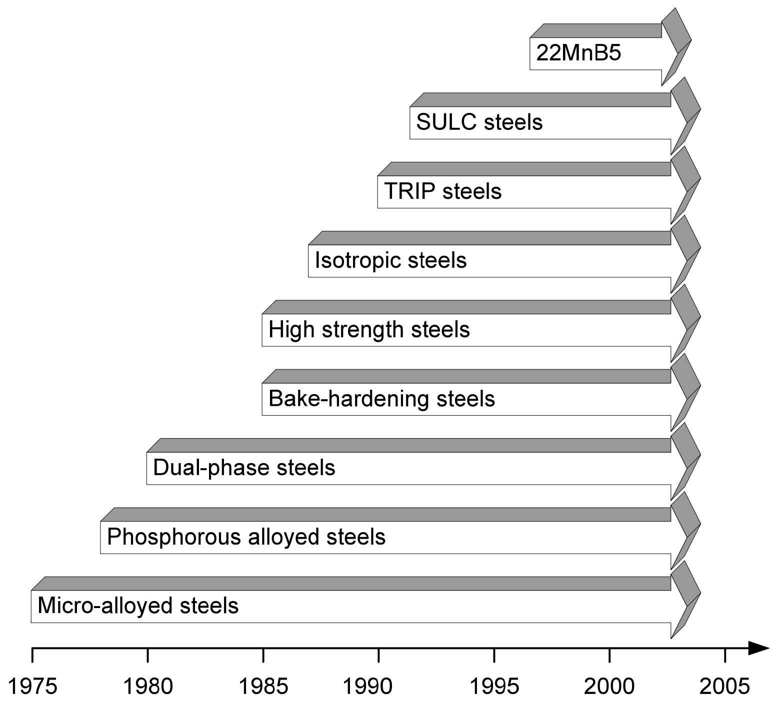

Figure 1. Steel development in the automotive industry in the last 30 years

We can analyse these development trends from another aspect as shown in Figure 2. where the well-known relationship between strength and ductility parameters for conventional low- and high strength steels can be seen.

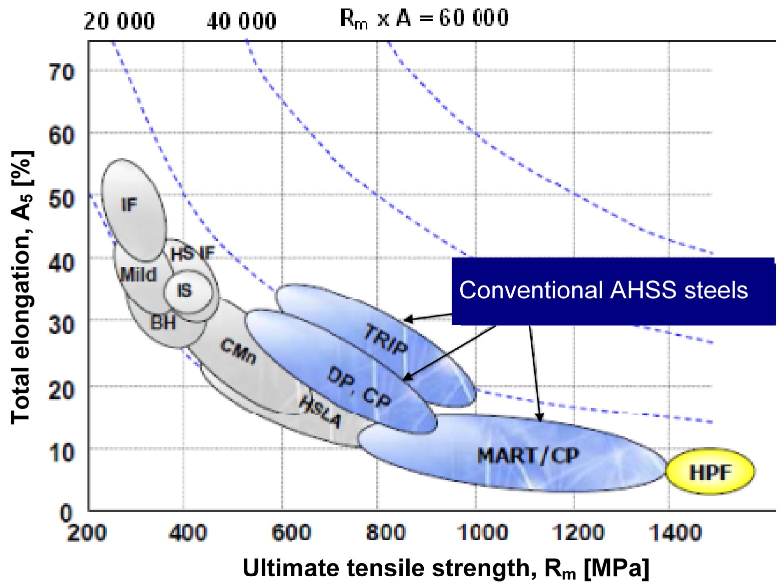

Figure 2. Ultimate tensile strength vs. total elongation for conventional high strength steels

From Figure 2. it may be seen that the product $R_m \times A_{80}$ (where R_m is the ultimate tensile strength and A_{80} is the total elongation) is a constant and thus follows a hyperbolic function. The constant ($C = R_m \times A_{80}$) for these steels is changing between 10 000 to 20 000 and we can state that these developments may be regarded as one of the most important results in the second half of the last century in achieving the required mass reduction. It is also worth mentioning that for these new high strength steels the increase of strength parameters is much more significant than the decrease of the ductility parameters [3]. This is particularly valid for the group of steels marked as *Conventional AHSS steels* in the figure. Dual Phase steels (DP), Complex Phase steels (CP), Martensitic Complex Phase steels (MART/CP) and TRIP steels belong to this group that gain wide application in car body production.

2.1. New Generation Advanced High Strength Steels

Besides the before analysed steels, there are even more pronounced steel developments in the last two decades. The two most outstanding representatives of Advanced High Strength Steels are the so-called Extra-Advanced High Strength Steels denoted as X-AHSS, and the Ultra-Advanced High Strength Steels denoted as U-AHSS. There are several subgroups within these steels. The development and application of these X-AHSS and U-AHSS steels is evolving from the ever increasing demand on the car manufacturing to produce cars with even lower consumption and less harmful emission simultaneously with more safety and higher formability.

As we could see analysing the various grades of conventional high strength steels, the constant of the product of tensile strength times total elongation (i.e. $C = R_m \times A_{80}$) for that group was increased from C = 10,000 to C = 20,000. These X-AHSS and U-AHSS steels represent another order of magnitude as shown in Figure 3. In this figure, it can be well seen that the constant $C = R_m \times A_{80}$ has been increased to C = 40,000 for X-AHSS steels and to C = 60,000 for U-AHSS steels. Obviously, these values are mean values; the various subgroups of both X-AHSS and U-AHSS steels cover a broader range as shown in Figure 3., too. In this figure, the conventional high strength steels analysed in the previous section are also shown, which provide a good basis for comparison how big development in AHSS steels achieved. Considering these extreme large values (C = 40,000 to 60,000) it means that with the same value of total elongation the strength can be doubled or tripled, which has a priceless value to meet the increased strength requirements in car manufacturing to reduce the weight.

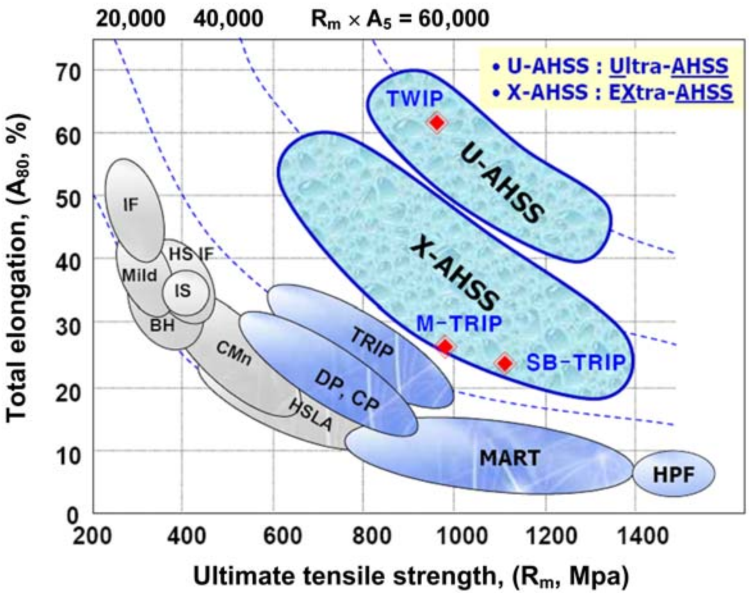

Figure 3. Tensile strength vs. total elongation for X-AHSS and U-AHSS steels [3]

The extra high strength steels (X-AHSS) may be regarded as the further development of TRIP steels: these X-AHSS steels first appeared in the car manufacturing in the production range of the Far-

East car manufacturer superpowers, in Japan and Korea. There are three subgroups in these steels, namely the so-called FB-TRIP, the SB-TRIP and the M-TRIP.

The microstructure of FB-TRIP steels contains ferrite (F) and bainite (B) as indicated in their name (FB stands for Ferrite-Bainitic TRIP steel). Ferrite assures large value of stretchability, while the high strength is provided by the bainite produced by extra high grain refinement. This microstructure besides the high strength values results in outstanding strain hardening (n) and in large total elongation.

The microstructure of SB-TRIP steels (which is termed as Super Bainitic TRIP steel) has small nano-sized, lamellar bainite matrix with a small amount of retained austenite. Their mechanical properties can be characterised by extra high strength parameters ($R_{p0.2}$ = 900 MPa, R_m = 1600 MPa) with outstanding total elongation (A_{80} = 27-30 %) at this extra high strength values.

The third subgroup, i.e. the M-TRIP steels contain also small amount of retained austenite but in martensite matrix, which lead to an even higher strength with still relatively good total elongation values. The usual composition of the M-TRIP steels can be characterised by C = 0,15-0,2 %, Si = 1,6 %, Mn = 1,6 %.

Ultra Advanced High Strength steels (U-AHSS) can be found on the top of today's steel development. TWIP (Twinning Induced Plasticity) steels are the most characteristic representatives of this group. TWIP steels usually contain high manganese content (Mn = 17-24 %). This high manganese content provides the fully austenitic microstructure at room temperature. Its deformation mechanism may be characterised by the large number of deformation twinning induced by the plastic deformation. It has also very high strain hardening capability ($n = 0.4$), which is responsible for the extra-large uniform elongation (ε_m = 50%) besides the extreme high strength parameters (R_m = 1000-2400 MPa). It is also worth mentioning that for example at tensile strength R_m = 1000 MPa they have a total elongation of A_{80} = 65 %, which means that the product of $R_m \times A_{80}$ may achieve the constant C = 65,000, which is the highest value among steels at present.

3. Application of non-ferrous metals and alloys, as well as non-metallic materials

Due to the increasing demand for environment-friendly vehicles requiring reduced fuel consumption and weight, besides steel as structural material, aluminium alloys in automobiles are recently also widely used in car manufacturing for body-in-white production, and their ratio will even further increase according to the application trends shown in Figure 4.

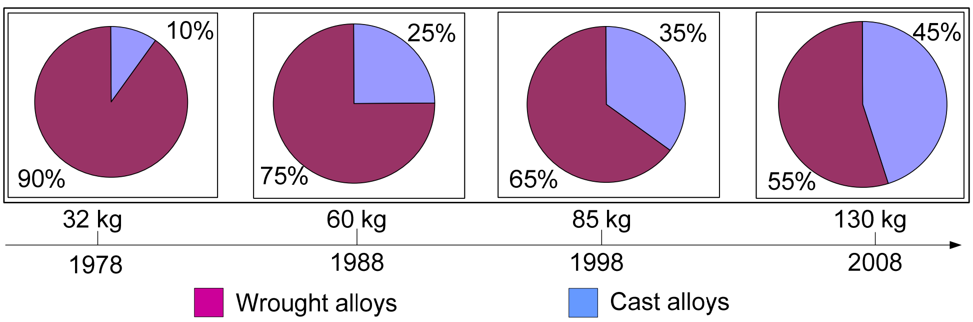

Figure 4. Application trend of Aluminium alloys in car manufacturing

It can be well seen from this figure that the application of aluminium and its alloys has been increased more than four times during the last 30 years. While in 1978, the total amount of aluminium applied in car manufacturing was about 32 kg in an average car, for 2008 it was increased up to 130 kg. It is also worth mentioning that the sort of aluminium alloys has also been significantly changed. While in 1978, the ratio of wrought Al-alloys was more than 90%, for 2008 this ratio has been significantly changed: today nearly 50-50 % is made of wrought and cast alloys. Even more significant changes can be observed if we focus on sheet materials. Due to the obvious advantages of aluminium alloys in mass reduction, there is an overall interest among car manufacturers to use more and more aluminium. Together with the mass reduction it means lower CO_2 emission and the reduction of fuel consumption.

It is also important to note that nearly all top car manufacturers (e.g. Mercedes, Audi, BMW) have at least one model where the body is made of aluminium alloys. Most of these models belong to the luxury car category, but recently there are already aluminium bodies in the compact car category, too. In many cases aluminium alloys are used within the so-called multi-material concept as shown in **Hiba! A hivatkozási forrás nem található.**.

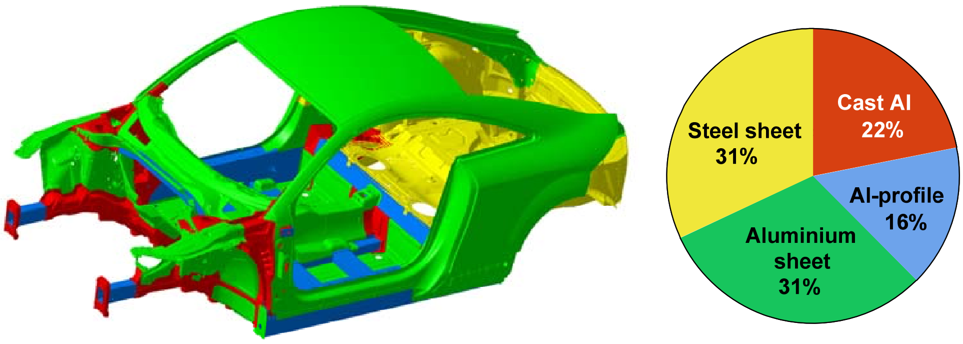

Figure 5. Multi-materials body concept in car manufacturing [8]

Many analyses also have shown that further significant weight reduction can be achieved in automobiles using fibre-reinforced composite materials. Carbon-fibre reinforced polyamide seems to be particularly suitable for this purpose: it satisfies the requirements of production in large series together with good mechanical strength and shape stability.

In Table 1. the comparison of materials application trends in car manufacturing is shown concerning various parameters. From this Table, it can be seen that during the last 35 to 40 years the average mass of cars has been decreased by 39%, though ferrous metals still remained the most important materials, very dynamic increase of aluminium and other light metals, as well as in polymers can be observed.

Table 1. Comparison of material application trends in car manufacturing

	1975	2000	Changes in %
Average mass (kg)	1800	1100	-39 %
Ferrous metals	60-65 %	45-50	-(23-25) %
Al and other light metals	3-5 %	10-15 %	(200-233) %
Polymers	10-15 %	20-22 %	(100-200) %
Other (glass, textile, etc.)	15 %	13	-13 %

4. Conclusions

In this paper the recent development trends in sheet metal forming were overviewed from the point of view of material developments.

Concerning the material research and development the increasing application of high strength steels, low density aluminium alloys, as well as the so-called multi-material concept was emphasized. Among high strength steels both the so-called conventional high strength materials (like HSLA, Dual-Phase, Complex Phase, and TRIP steels) were analysed. Besides introducing the development trends in steel materials in the last 35-40 years, a special emphasis was given of the most recent developments in Advanced High Strength Steels, as the Extra- and Ultra High Strength steels.

It was also shown that the application of aluminium alloys in car manufacturing is rapidly increasing. Finally, the multi-material car concept was introduced.

5. Acknowledgements
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