Lightweight Manufacturing of Automotive Parts

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Abstract. In this paper, some material developments and its demands in sheet metal forming for automotive industry will be overviewed. It is not easy to match and meet good performance, low consumption, low emission and high safety with comfort simultaneously, only by applying conventional materials and processes. Due to these factors and needs, continuous material and technological developments in sheet metal forming are required.

1. Introduction
The automotive industry is the one that most drives the constant development in sheet metal forming processes. Due to the constant demand of the automotive market to reduce cost of production, customers’ wishes, institutions and groups aiming at reducing pollutant gas emissions and protecting the environment, reducing the weight of automobiles is crucial, this is the reason why the application of lightweight manufacturing principles has a huge importance.

The automotive sector is in a constant impasse trying to balance excellent performance, economy, comfort and reduction of polluting gases. These contradictory requirements are the fundamental impetus for the challenging advances that today's engineering needs to address.

It is well known that by increasing the strength of materials, the formability decreases considerably, however the formability of cars components or parts is regarded as one of the most important issues in car manufacturing. During the last years, significant advances and changes in high strength steels and various light weight alloys were achieved. The best examples of materials which achieved the requirements previously mentioned are, among high strength steels, the application of various dual-phase steels, while aluminum alloys are among light metals. However, the application of both aluminum alloys and light metals often leads to problems of manufacturing and formability. In this paper, it will be seen some innovations in metal forming processes and recent developments in materials related to sheet metal industry will be described [1].

2. The energy requirements for combined city/highway driving
Reduced consumption and less harmful emissions are also contradictory requirements. In order to ensure weight reduction, smaller sheet thickness should be applied, however, the requirement to increase safety is also in contradiction. The solution would be decreasing size, using high strength materials, what has unfavorable consequence, i.e. it would reduce formability [1].

In the figure 1, it can be seen the energy requirements for combined city/highway driving. In the figure the energy requirements are accounted for as part of the engine and parasitic losses [2].
3. Vehicle Advanced Structural Materials

A US D.O.E. comparison for the use of engineering materials shows that steel is still the most widely used material, with 725 million tons used each year. Aluminum and stainless steel are used at a rate of 20 and 14.5 million tons, respectively. Titanium is much less widely used at 0.04 million tons per year [1].

Although advanced light weighting materials are sometimes considered “high strength alloys”, strength is only one factor in evaluating a particular material substitution. A better measure is the “specific strength” – the material’s ultimate tensile strength normalized by its density. Additionally, many automotive components have structural stiffness specifications as the primary design requirement, so the proper parameter to consider is a material’s “specific stiffness” – the material’s elastic modulus normalized by its density.

Most of the engineering alloys in widespread use (steels, aluminum, magnesium, titanium) have nearly the same specific stiffness [1].

4. Effect of the material quality and the material properties

One of the most important trends in automotive industry is the application of light-weight design principles and methods. New materials are needed when new concepts in design are applied. In the last years, the application of high strength steel has been increased and new grades have been developed. However, it is known that by increasing the strength the formability decreases.

Several micro-alloyed and phosphorous-alloyed steels are currently used, with and without bake-hardening. In the figure 2 it can be clearly observed an increasing use of dual-phase, TRIP-steels, interstitial-free (IF) and ultra-low and super ultra-low carbon steels.

Figure 1. The energy requirements for combined city/highway driving [2]
The figure 2 demonstrates the total elongation (A) versus ultimate tensile strength (MPa).

![Graph showing total elongation versus ultimate tensile strength for conventional high strength steels][1]

Figure 2. Tensile strength vs total elongation for conventional high strength steels [2]

From figure 2 it can be seen that the product of $R_m \times A_{80}$ is a constant and thus follows a hyperbolic function. The constant $C$ ($R_m \times A_{80}$) for these steels changes between 10000 and 20000 and this result shows that the mass reduction was achieved during the second half of the last century. It is also important to mention that the new high strength steels increased much more significantly their strength parameters compared with the decrease of their ductility parameters. This is valid for the conventional AHSS steels present in the figure (TRIP, Martensitic Complex Phase, Complex Phase and Dual-Phase steels (DP) [2].

5. Dual Phase (DP) Steels

Though HSLA steels present incredibly good properties, their good formability is not always sufficient to produce parts that need to have a large plastic deformation. This is what motivated the creation of a new grade of high strength steel.

One example is the Dual-phase steels, which consists of ferritic matrix containing hard martensitic second phases. These are found in small martensite islands form, as it can be seen in figure 3. By increasing the volume fraction of hard martensite phases the strength is also increased. Controlling the cooling from the two phases austenite and ferrite zone, the dual-phase structure can be produced. [2]

When the ratio of martensite / ferrite is modified, the mechanical properties of DP-steels can be changed in a significant interval, where the normal percentage of martensite isles is between 10 and 20%. While the process of forming occurs, in the low-strength ferrite phases deformation is concentrated and it is surrounding the martensite isles and then extra high strain hardening of DP-steels is created. Compared to conventional HSLA steels, it is achieved a result of a much higher ultimate tensile strength allying the excellent ductility with extra high strain hardening. Another important advantage of DP-steels is the high bake hardening effect. After painting in the bake oven, their yield strength increases considerably due to the temperature [2].

In the figure 3 it can be seen both hard martensitic isles and mild ferrite matrix. Where the martensitic isles are small dark grains and the ferrite matrix are the light grains. Excellent ductility is assured by the formation of a continuous micro-structure formed by mild ferrite, while high strength of dual-phase results from hard martensite [2].
6. New Generation Advanced High Strength Steels

The two most outstanding example for advanced high strength steels are the extra-advanced high strength steels (X-AHSS) and ultra-advanced high strength steels (U-AHSS), and there are many subgroups within them. There is an increasing demand on the car industry, that stimulate the development and application of X-AHSS and U-AHSS.

In the figure 4 it is demonstrated another order of magnitude represented by X-AHSS and U-AHSS. For conventional high strength steels, the constant of the product of tensile strength times total elongation was increased from 10000 to 20000. The various subgroups of both X-AHSS and U-AHSS steels cover a broader range as shown in figure 4. Taking into consideration the values $C = 40000$ and $C = 60000$ it can be noted a big achievement in AHSS steels developments. This means that, with the same value of total elongation, the strength can be twice or three times bigger, what is really important in order to meet the required strength in reducing weight in cars. The X-AHSS may be regarded as the further development of TRIP steels. The three subgroups in these steels are FB-steels, SB-TRIP and M-TRIP. The various subgroups of both X-AHSS and U-AHSS steels cover a broader range as shown in the figure 4.

Figure 3. Schematic microstructure of DP steels [2]

Figure 4. Total elongation (A80) vs Ultimate tensile strength (Rm) for various generations of high strength steels [2]
In the figure 5 and 6 two models made of aluminium alloys are presented (Mercedes SL and Audi A2) [4].

![Figure 5. Mercedes SL aluminum body [4]](image1)

![Figure 6. Audi A2 aluminum body [4]](image2)

Figure 7 shows the proportion of aluminum alloys application used within the multi-material concept.

![Figure 7. Multi-material body concept in car industry [4]](image3)

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 because it satisfies the requirements of production in large series with good mechanical strength and shape stability [4].

7. Vehicle Mass Distribution

Several studies have examined the mass distribution within typical vehicles. About 43% of the total vehicle mass, is the single heaviest group; followed by the powertrain and chassis, in almost equal proportions, at 27% and 26%, respectively. More recently, it was also found that within the body group, the unit-body or body-in-white (BIW), is the single largest component, with about 28% of the total vehicle mass, while glass is 3%, the interior 10% and 4% others [1].

8. BIW (body in white) concept

Nowadays, among all important requirements mentioned before, the formability for new materials should be strongly considered in BIW (body in white) concept.

It is of great importance to find a good balance between strength and formability properties, as using higher strength materials the formability decreases. The ultimate tensile strength and the total elongation has a hyperbolic relationship, i.e. lower strength with better formability and higher strength with lower formability. One of the main tendencies in the automotive industry is the application of light-weight design principles, what from the side of materials science, can be met by applying materials with high specific strength (UTS/ρ) and high specific stiffness (E/ρ). Considering these properties, the application of high strength steels, light metals and alloys (particularly aluminum and magnesium), as well as an increasing amount of various non-metallic materials is fundamental [1].
The figure 8 shows a scope of stamped components for BIW and chassis components [6].

**Figure 8.** Scope of stamped components for BIW and chassis [6]

9. **Hot forming for BIW components**

Hot forming is increasingly popular for BIW components – driven by increased strength and mass reduction requirements. The figure 9 shows a comparison of share of hot-stamped steel in BIW – Sample vehicles (%) among a few models [6].

**Figure 9.** Share of hot-stamped steel in BIW – Sample vehicles (%) [6]

Increasing share of hot-stamped steel in BIW is driven by certain beneficial attributes, including:
- High strength and crash resistance at relatively low cost
- Low weight due to reduced material thickness
- Reduced spring-back during manufacturing process (common in cold-forming process)
- Best weight savings per additional cost compared to Aluminium and plastic composites
In addition, within specific models (figure 10): e.g. In the Mazda 2, the current model has an approximate 30% share of hot-stamped steel, beating its predecessor model (approximately 10%) – parts made of hot steel include A-pillar, roof frame and rocker panels [6].

Figure 10. Crash regulations in Europe and US [6]

Past initiatives to improve vehicle safety have already led to major changes in material use and BIW component design.

In Europe and the US, the market is driven by safety performance assessment programs such as Euro and US NCAP – European car manufacturers OEMs aim for top 5-star ratings due to high customer awareness:

- In the past, Euro and US NCAP test requirements have focused on driver and passenger safety, with a high impact on BIW components – both material usage and component design were affected.
- Future tests are expected to focus more on pedestrian safety and driver assistance programs.
- This will not be majorly disruptive for BIW/chassis components, but
  - New required functionalities will have to be integrated (e.g. "intelligent hoods")
  - OEMs will be looking for materials that ensure a high level of design freedom, as design and specifications are impacted by the regulations.
10. Targets for the EU related to CO₂ emissions

In July 2012, the European Commission came forward with a regulatory proposal to set a 2020 target of 95 g/km for newly registered vehicles. The regulation was formally adopted in March 2014. It sets individual targets for manufacturers, depending on the average vehicle weight of a manufacturer’s fleet, and requires all manufacturers to reduce CO₂ emissions by 27% compared to their individual 2015 targets and the regulation will be phased in later, so that only in 2021 all vehicles will be taken into account [5].

EU and NAFTA outsource BIW components more often than Asia - Overall, surface components outsourced less than other components as seen in the figure 11, Current outsourcing rate, 2015 and future development (%) [6].

10.1. Future development of the market and implications [6]

As it can be seen in the figure 12, the total global market for BIW & chassis stamped components is EUR 103 bn – Approximately 15% of the total component market.
The figure 13 gives an outsourcing rate, which is expected to grow over the next decade – Global market will be worth around EUR 63 bn in 2025 [6].

![Figure 13](image)

**Figure 13.** Total market, OEM captive vs. outsourced, 2015-25 EUR bn, (%) [6]

The total market will grow in line with global vehicle production (CAGR ‘15-’25 2.4%). For suppliers, the addressable market will grow faster than the total market due to increasing outsourcing rates (42% in 2015, estimated 49% in 2020).

Component prices assumed constant over time, as material costs are typically indexed, and minor year-on-year price reductions are balanced out by evolutionary product innovations). EU and NAFTA account for around 70% of the BIW and 50% of the chassis market – Both shares are shrinking as China expands, figure 14 - Addressable market by region, 2015-25 [EUR bn ( %)] [6].
Figure 14. Comparison between BIW and chassis (prediction between 2015 and 2025) [6]

11. Share of hot stamping in total BIW market is expected to grow
The figure 15 shows the share of hot stamping in total BIW market prediction for the future. Share of hot stamped parts in total BIW (%) of market value [6].

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