POTENTIAL APPLICATIONS OF NEW HSS GRADES FOR WHEELS

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ABSTRACT

It is now accepted by all automotive and truck OEMS and suppliers that AHSS (Advanced High Strength Steels) are one of the main answer to the stricter and stricter requirements of safety and environment (lightening). The potential of AHSS can be resourcefully exploited only through a strong effort from the designers and the manufacturers towards analysing all aspects regarding their use in production from both product and process points of view. Since the middle nineties AHSS are being used for wheel production, and MAGNETTO WHEELS, as both designer and manufacturer of wheels, has earned a good experience about their potential and the limits of their application to its products.
This paper is focused on underlining the great benefits of AHSS wheel, in terms of weight reduction, increased performance under load and new possibilities to satisfy style requirements, and analysing the major critical aspects linked to industrialisation.

KEYWORDS

wheel, fatigue, stiffness, style, flow-forming, skeleton, spoke, steel, multiphase, trip, boron, manganese, stainless, AHSS

INTRODUCTION

Wheels are car products (figure 1), with key geometrical and structural specifications. The wheel must satisfy not only load fatigue resistance and weight requirements, but also several other conditions related to the installation to the vehicle (like geometry, stiffness and environment resistance).
In addition to these specifications, new requirements of style and weight are coming from the OEM's. In order to accomplish such stricter requirements, the wheel supplier must have a deeper insight into new materials and manufacturing processes. The whole implication of the potential use of new materials and processes has to be deeply investigated, for a complete product-process integrated design methodology.

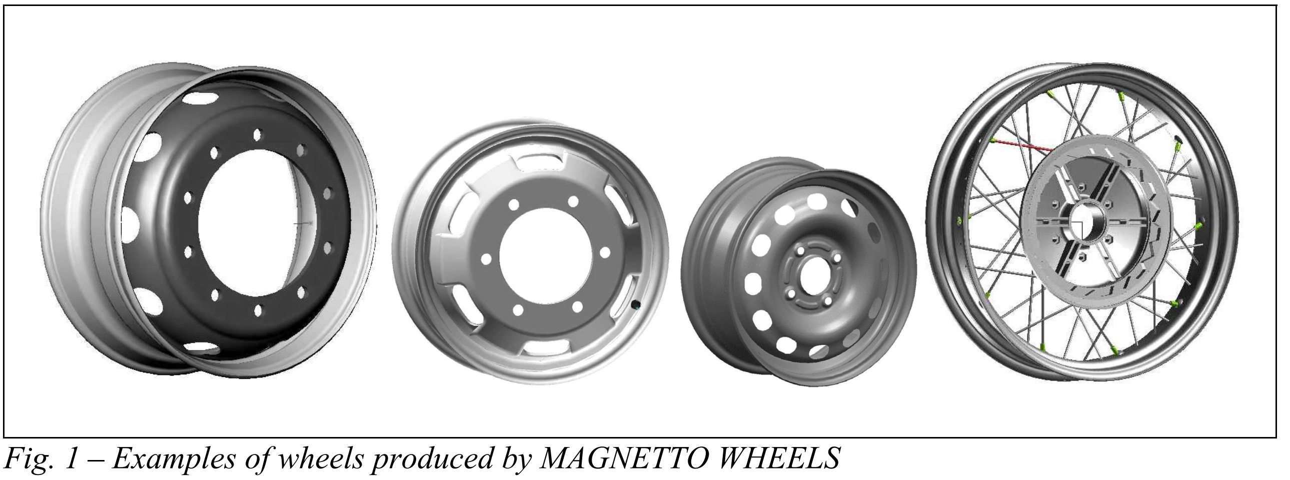

Fig. 1 – Examples of wheels produced by MAGNETTO WHEELS

The manufacturing processes regarding steel wheels are separated into two categories: standard sheet metal forming processes (such as progressive stamping, blanking, piercing, arc welding or machining) and dedicated processes (like flow-forming, spinning and circular profiling). The goal is getting with the lowest costs a safety component with the highest load carrying capacity and the lowest weight. AHS Steels help pursuing these targets, but, on the other hand, some of the design specifications of the wheel limit the complete exploitation of their potential use.
Obviously the costs must be continuously monitored, so as to avoid price increase not balanced by adequate performances increase. Within this frame, during the recent years, the materials used for the production of wheels have evolved from mild steel to ferritic – bainitic and multi-phase.
At the real beginning of this development process, the unique dimensioning principle was the fatigue resistance of the wheel, because all other requirements, such as stiffness and impact resistance, were implicitly satisfied owing to the high disc and rim thicknesses.
The increased fatigue limits of AHSS materials and the structural optimisation of the wheel were soon combined to new criticalities which designers have been obliged to face. The theoretical lightening potential of AHSS materials related to fatigue limit, compared to FeE355 steel - for wheels - is described in the following table.

Material	**Fatigue Limit**	**Lightening %**
FEE355	210 MPa	0%
FB450	250 MPa	12%
FB600 / DP600	275 MPa	19%
FB800 / TRIP800 / M800	360 MPa	33%
TRIP1000	450 MPa	43%

Tab 1. Fatigue limits and lightening potential of some AHSS, with respect to micro-alloyed FEE355

Considering, for example, the real case of a wheel 6½J x 15" H2, for which it is possible to use material grading up to 600MPa, the disc stamping sequence has been modified (figure 2) to satisfy the different FLD (figure 3) and minimise thinning in disc profile.

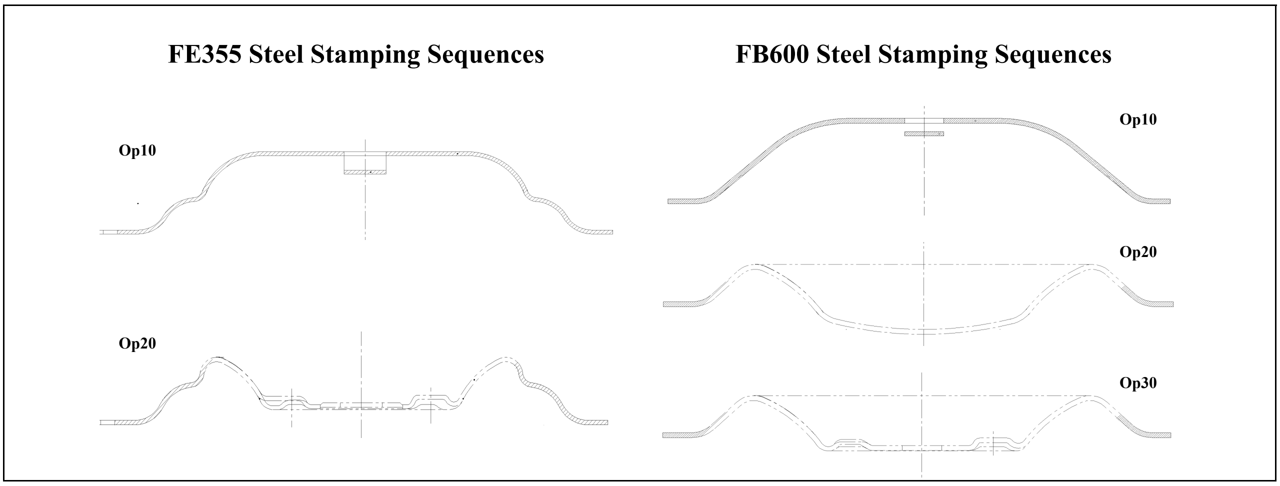

Fig. 2 – Comparison between cycles for manufacturing Mild and FB steels

Moreover, there are other technological process constrains related to the production of rims; for example, the rim forming process does not require high plastic deformation, but the present butt welding process limits material thickness value at minimum about 2 mm. Even so, the 21%

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lightening leads to a wheel weight of 7.2kg - for the considered wheel with rated load of 600kg - that is comparable to light alloy wheels.
Reducing thickness affects not only the fatigue behaviour but also other structural characteristics, as for example the rigidity of the bolt seats and the rigidity of the rims (burst test - impact test). Simple and reliable FE procedures have been developed in MAGNETTO WHEELS for these purposes (figure 4). The fretting phenomenon in the wheel/hub contact area, whose analysis requires the complete modelling of the hub, brake disc, wheel and bolts (bottom of figure 4), is also a big issue.

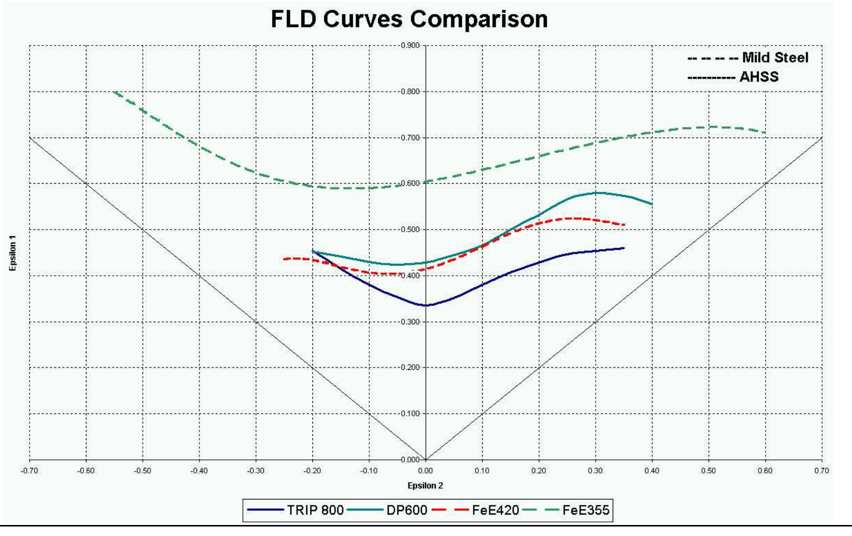
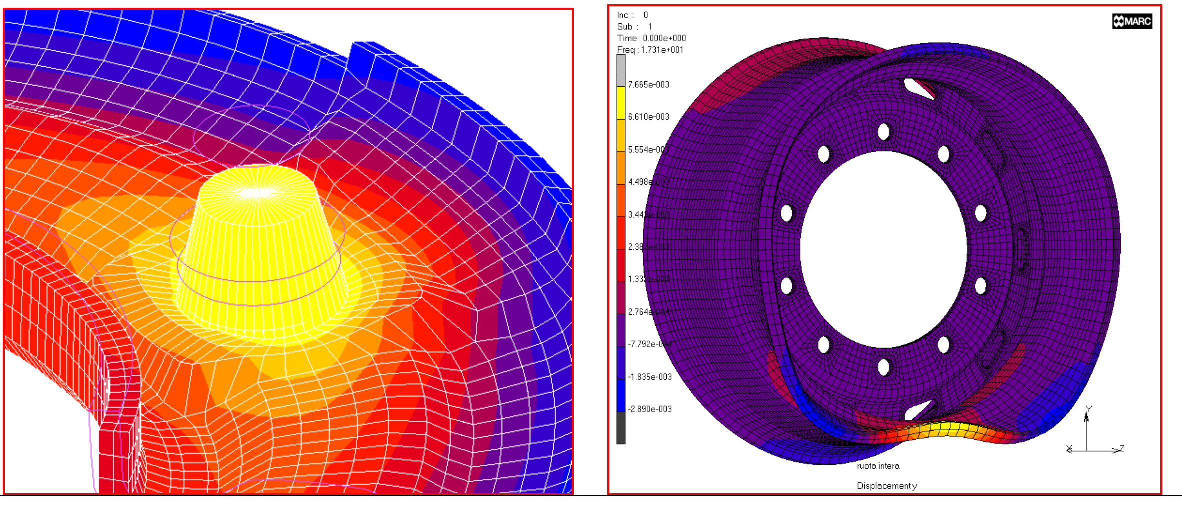


Fig. 3 – Comparison between forming limit curves of some steels

Bolt Seat Test FE Simulation **Burst Test FE Simulation**



Fretting Phenomena Example and FE Modelling

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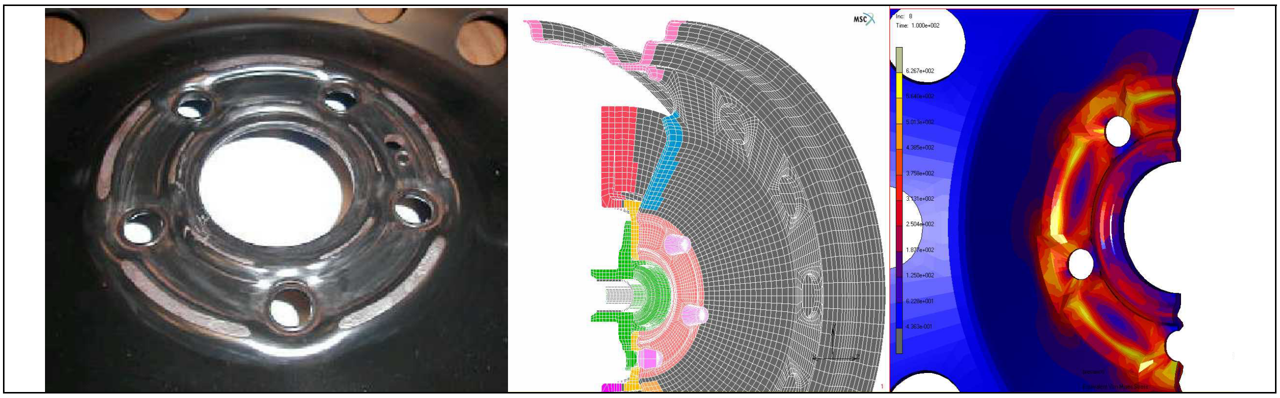

Fig. 4 – Examples of structural finite element analyses of wheels

Given all the above, the key point remains how to get the residual 20% lightening - or maybe even more - offered by new materials. The R&D of MAGNETTO WHEELS follows three approaches:

- exploring new discs materials and jointly designing the most suitable stamping process sequences;
- investigating and applying new technologies and modifying production process eliminating some technological constrains, in particular for flow-forming of rims;
- developing new wheel structures capable to take fully profit of the advantage of AHSS materials and satisfy fatigue and stiffness requirements.

1. EXPLORING NEW STEELS – EXPERIENCE WITH AUSTENITE STAINLESS STEEL

Among new materials, the most attractive ones are Boron, Manganese and stainless steels. Trials are on going in MAGNETTO WHEELS, aimed at verifying the process feasibility and the performances of discs produced with such steels. In any case, the cost factor is crucial, due to manufacturing of either the product (i.e. heating phase for Boron steels) or the raw material itself. MAGNETTO WHEELS is mainly focusing on evaluating the actual fatigue behaviour of products manufactured with these steels, i.e. how the fatigue resistance is influenced by the whole manufacturing process and how optimising the process for the best compromise cost-performance.
A recent experience with forming a disc with an austenitic stainless steel (AISI304L) thickness 3.38 mm, compared with DP600 thickness 3.55 used in production, proved the stamping feasibility, even with problems correlated with stamping with dies whose try-out was settled for DP600 and the reduced thickness. The forming tests aroused no problems of cracks and slight differences of formability between AISI304L and DP600, consisting in a higher value of springback (figure 5) and a slight increase of friction with the tools, for the former.

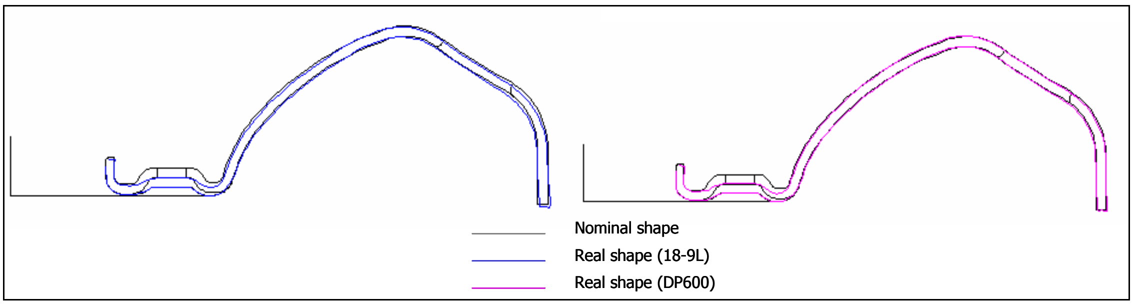

Fig. 5 – Comparison between radial section contours of discs in AISI304L and DP600

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Although AISI304L disks were produced with lower thickness (about 0.2 mm), AISI304L and DP600 disk wheels have the same fatigue behaviour (see table below). The fissures are comparable in size and position. Even with a welding process carried out manually with standard filler metal, the resistance to roll fatigue load is not likely to be affected by the quality of welding. Welding joint tests are still going on.

Test Type	Disc	Report	Weight [kg]	Cycles	Type and region of fissures
Rim Roll	18-9L	266,01	8,07	1.035.000	1 fissure starting from vent hole toward attachment face
	DP600	266,02	8,20	1.726.000	test suspended without fissures
Cornering	18-9L	266,03	8,05	177.905	2 circonferential fissures at attachment face next to bolt holes
		266,05	8,01	155.185	circonferential fissures at attachment face next to bolt holes
		266,07	8,04	137.130	circonferential fissures at attachment face next to bolt holes
			Average value	*156.740*	
	DP600	266,04	8,19	134.770	circonferential fissures at attachment face next to bolt holes
		266,06	8,17	183.190	3 circonferential fissures at attachment face next to bolt holes
		266,08	8,19	139.940	circonferential fissures at attachment face next to bolt holes
			Average value	*152.633*	

Tab 2. Results of roll and cornering fatigue tests of DP600 and AISI304L disks wheels

The resistance to the bolt seat test is very good. The AISI304L disk bolt seats resist more than DP600 disks of about 250 kg (figure 6)

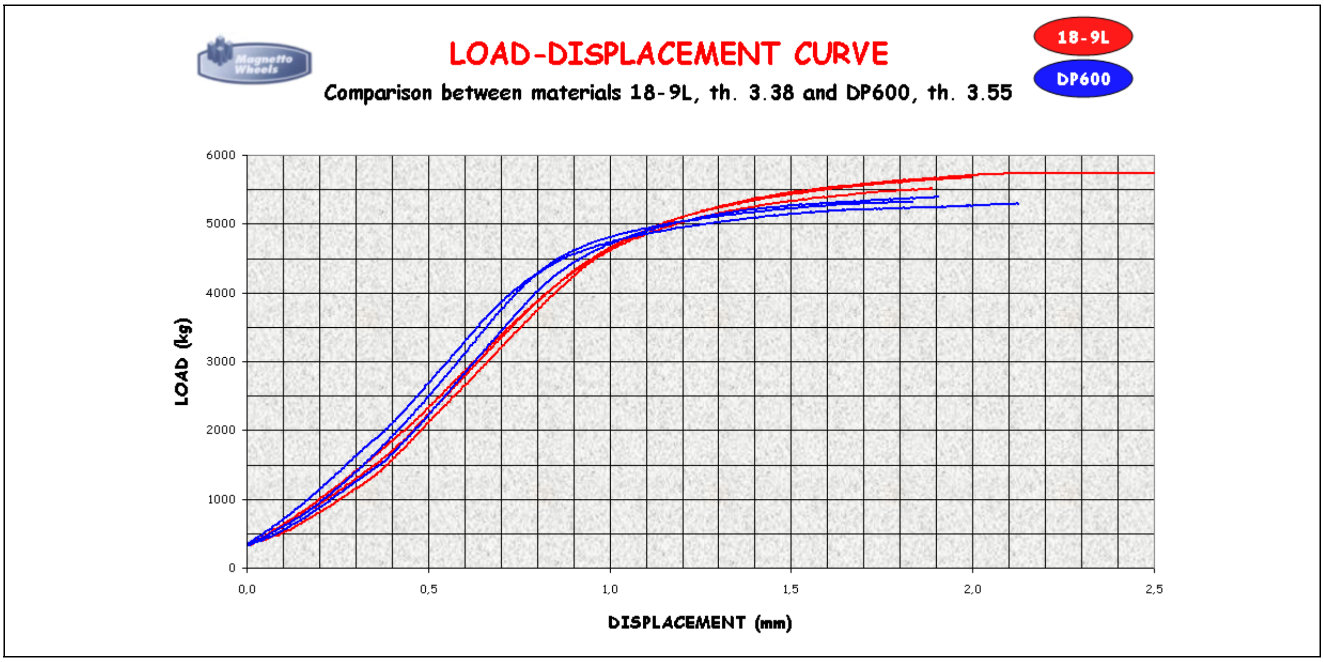

Fig. 6 – Results of bolt seat test performed on DP600 and AISI304L disks wheels

In conclusion this experience proved that stainless steel discs produced with reduced thickness and therefore with a lower weight of about 180 grams (about 2%), with respect to DP600, have no serious forming criticalities and can fulfil all product specifications of fatigue and static resistances.

2. APPLYING NEW TECHNOLOGIES – EXPERIENCE WITH FLOW-FORMING OF AHSS RIMS

The rim production process has rapidly changed in the last four years. A new process step has been introduced to vary locally the rim thickness after butt welding. This procedure has two effects: the spinning process increases the material mechanical characteristics and it is possible to rule the rim

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thickness and the wheel rigidity. Even if the material used in this process is typically FB450 (in some cases FB600), the flow-formed areas have a UTS of 700MPa or more. The possibility to cross the 2mm thickness limit leads to steel wheels lighter than light alloy wheels (figure 7).
Flow-forming represents a powerful technology for the production of lightweight optimised wheel structure, allowing for a better distribution of the material thickness along the profile (figure 8).
The technology is already used for the manufacturing of truck discs prior to assembly with the rim. The same technology presents high potential in order to thin non critical areas of the rim to lower the total weight of the wheels. The last application is very promising for lightweight design, taking into account that the rim represents the 60 % of the total wheel weight and that only some of rim areas require high thickness value (critical areas). This is the reason why it will be soon used for light steel rims (as an example the future Laguna steel rim).
The fatigue behaviour of the safety component "wheel" always represents the most important and mandatory requirement to be satisfied. Flow-forming introduces high strains, material flow, hardening, modification to the surface quality, which can affect the fatigue performance of the wheels. As a consequence, the influence of the process parameters and material characteristic on the fatigue behaviour, has to be analysed, especially if new generation HSS are utilised to contribute to the weight reduction.

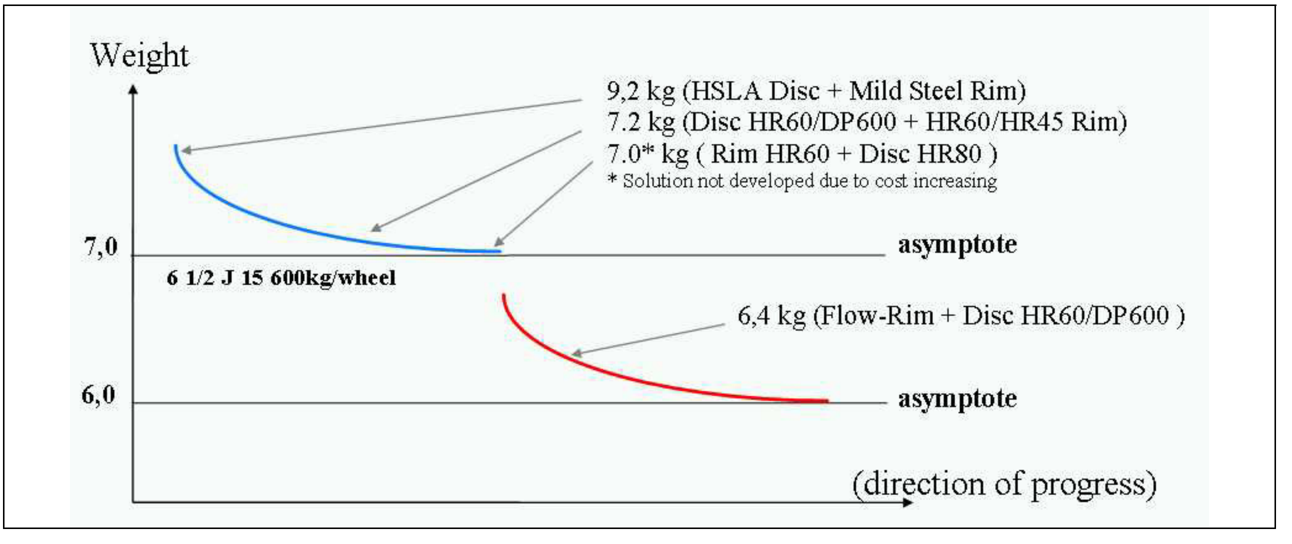

Fig. 7 – Breakthrough in the production of lightweight wheels by flow-forming

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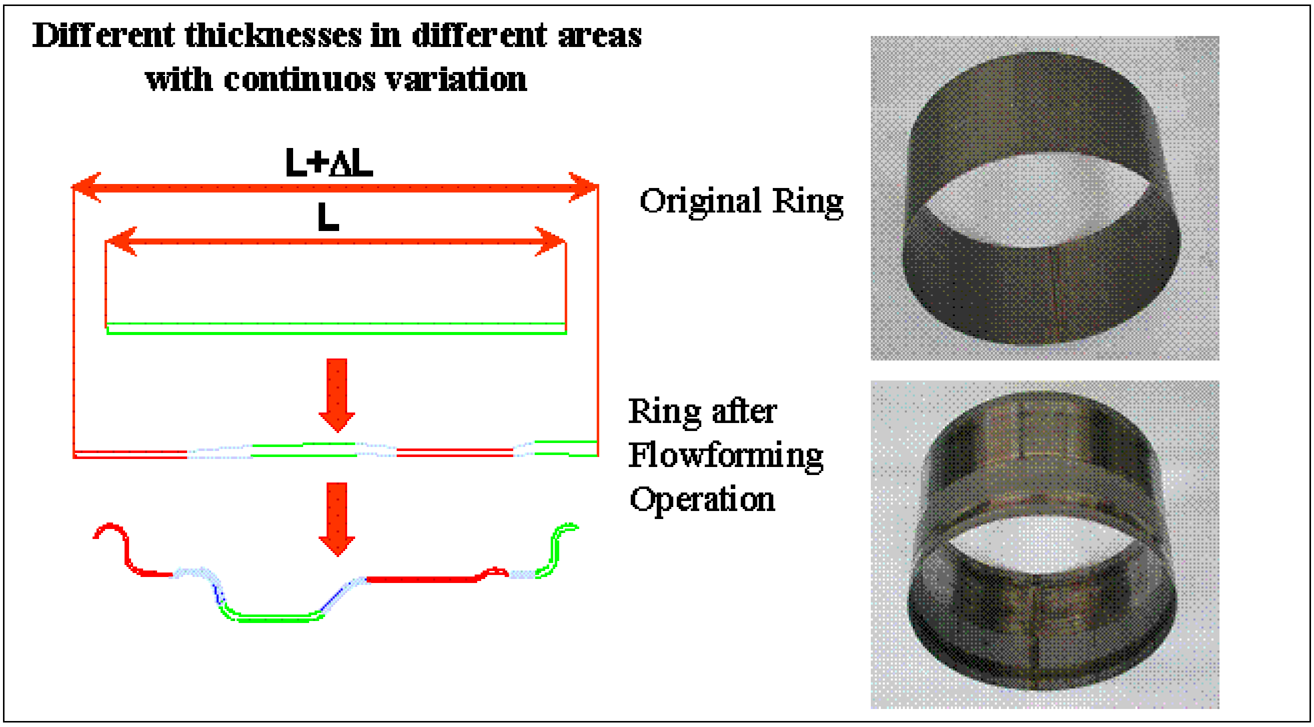

Fig. 8 – Distribution of thickness along axial section of ring before and after flow-forming

The key factors to manufacture high quality flow-formed products largely depends on the appropriate processing of the starting material, its metallurgical parameters and the selection of suitable flow-forming machine parameters. The parameters such as spindle speed, roller feed rate, reduction per pass and the geometry of the forming rollers (the angle of attack, relief angle, and nose radius) and the stagger setting of rollers are very important.
From the other side, the high loads transferred to the tools during the process as well the use of high strength steels cause rolling wear and failure of the rollers after short life. MAGNETTO WHEELS are examining the issues of process optimising for fatigue of both rims and rollers, respectively through participating in two research European projects: “HIFLOW” and “METHODWEAR”. The first one is aimed at studying the “influence of flow-forming process parameters on the fatigue behaviour of high strength steel wheel for automotive industry”. One of its outputs is the definition of the methodology for flow-forming simulation (figure 9) and a procedure, which allows taking into account flow-forming process effects for the analysis of fatigue resistance of the final wheel (figure 10).

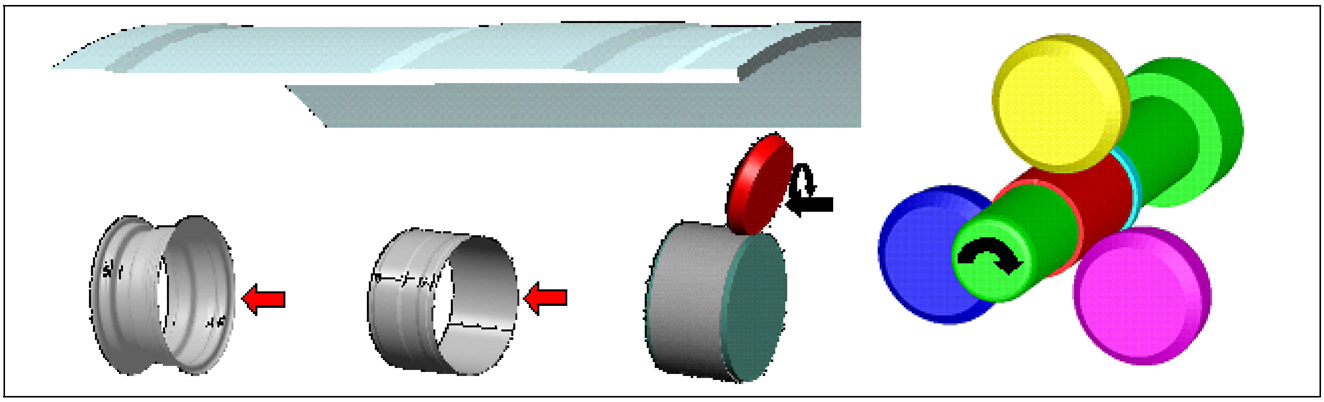

Fig. 9 – Modelling Flow-forming process for Finite Element Simulation

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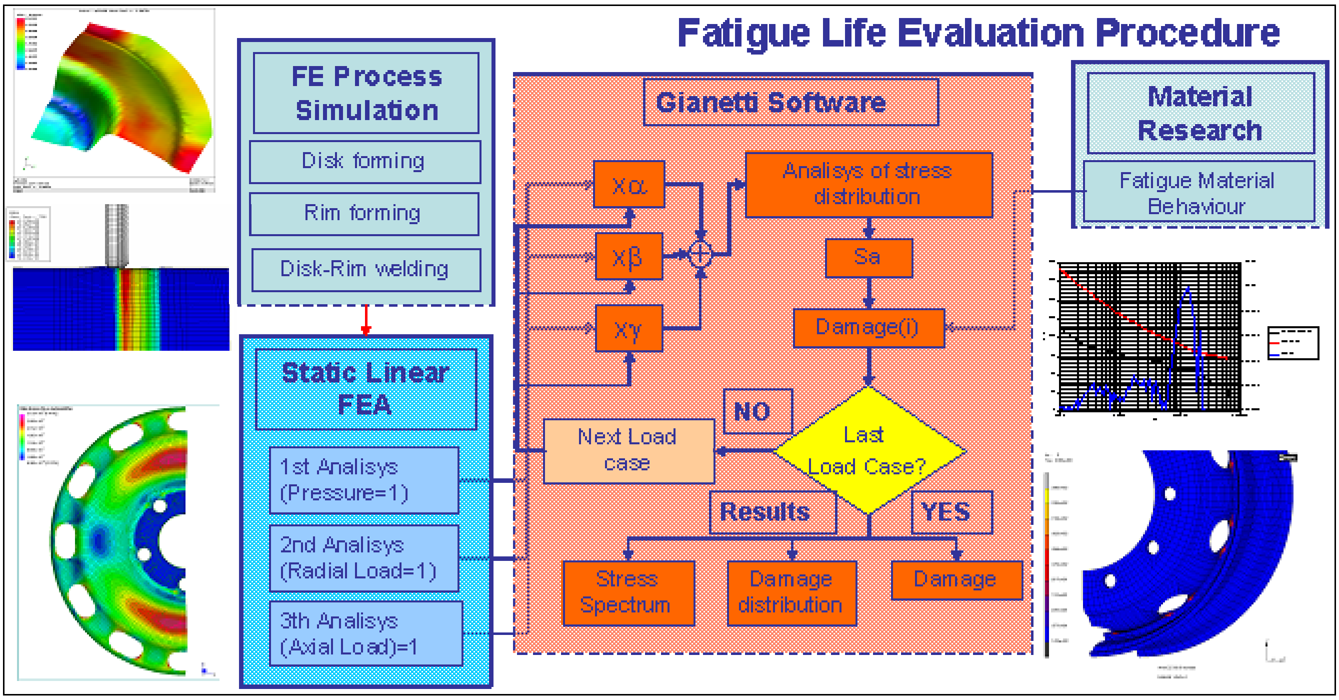

Fig. 10 – Fatigue life evaluation procedure

An open issue yet under investigation is the capability of some AHSS, especially the multiphase steels, to resist the high loads due to flow-forming, as the process induces very large strains. The problem is manifest about the butt welding line heat affected zone of multiphase steels. In fact, these steels can suffer a high decrement of mechanical properties due to welding thermal effects, due to their high equivalent carbon value (M800, $C_{eq,\ max} = 0.55$), compared to ferritic-bainitic steels (FB600, $C_{eq,\ max} = 0.39$). As a consequence, as it has been experienced, the high strains induced by flow-forming can arouse ruptures along the rim welding line. That is being avoided by a suitable choice of process parameters. Besides, alternative welding technologies are being taken into consideration, like autogenous and hybrid laser welding, whose employment is being tested also for disk - rim assembling.

3. DEVELOPING NEW WHEEL CONCEPTS

Another way to exploit AHSS materials is to re-think completely the wheel structure. The case study of MAGNETTO WHEELS is a high loaded truck wheel sized 22.5”x11.75 with 4.500 kg rated load. The idea is developing a wheel with a steel “skin”, filled with a polymer, with the only function of imposing the skin distance. This has been defined, in one word, as a “sandwich wheel”.
In case the running trials will be completed with positive results, the solution will be applied to passenger car wheels too (figure 11). The sandwich wheel for passenger cars also offers a high styling potential and could even be developed with valuable materials like stainless steel.

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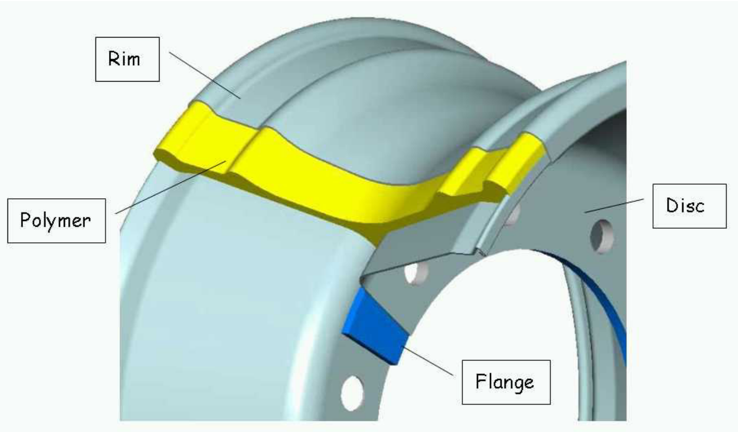
Sandwich Truck Wheel



Sandwich Passenger Car Wheel

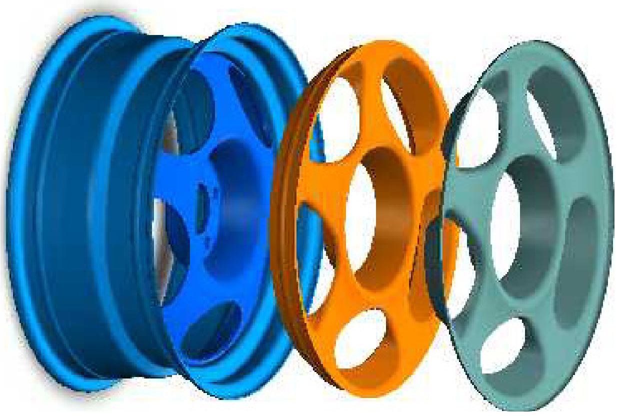


Fig. 11 – Example of sandwich steels for trucks and cars

To complete this overview on AHSS materials in the production of wheels, also the style issue shall be considered: a new generation of styled steel wheels has been developed, that, additionally to style, also offers a further reduction of weight, comparable to light alloy wheels. Figures 13 and 14 show two examples of style wheels: the "full face" and the "spoke" or "skeleton". The first idea of spoke wheel was born due to the necessity to create steel wheels with shapes as similar as possible to alloy wheels, whose main element is style, but characterized by lower weights and especially lower production costs. At the moment MAGNETTO WHEELS started a project of a 7J x 17" spoke wheel and is being performing the first production trials.

This project is completely innovative and involves great difficulties relative to the designing phase and the production feasibility. If one compares the tensional behaviour of a spoke wheel with the one of a standard wheel, both subject to the same load (for example a rotating bending moment), in the spoke wheel the disc shows much higher stress levels than in standard one with a common optimized disc profile. This phenomenon is due to the complex geometry of spokes and the great sizes of vent holes and involves the necessity to employ high-grade materials and great thicknesses in spoke wheels discs.

Therefore, the tooling design for the disc production becomes also really difficult and requires a very deep analysis of both process and product, taking into account mechanical characteristics of disc materials to improve the wheel performances in fatigue tests and guarantee acceptable safety ranges also with reduced disc thicknesses, while assuring process feasibility, with acceptable costs.

Fig. 12 – New concept of style wheel: "full face"

Fig. 13 – New concept of style wheel: "skeleton"

4. CONCLUSIONS

The potential of AHSS steels can be exploited efficiently only through a strong effort from the designers and the manufacturers to analyse all aspects of their use in production from both product and process points of view. The approach used by MAGNETTO WHEELS, as both designer and manufacturer of wheels are:

- exploring new discs materials and jointly designing the most suitable processes;
- investigating and applying new technologies, like flow-forming of rims;

- developing new wheel structures to fulfil requirements of fatigue, stiffness and style as well.

MAGNETTO WHEELS started R&D projects to explore Boron, Manganese and stainless steels. The recent experience with stainless steels proved that discs produced with not modified dies, with this material and reduced thickness, have no serious forming criticalities and can accomplish all product specifications. The demonstrated lightening potential of AISI304L stainless steel is at least 2%, with respect to DP600.

By flow-forming, high strength high precision thin walled tubes with good surface finish and close tolerances can be manufactured with relative ease and reasonable costs. The manufacturing process is automated to give consistently reliable products with the availability of latest 4-axis CNC heavy-duty flow-forming machines. The requirement of minimum tooling and the outstanding design flexibility the process offers are well suited for manufacturing the “rim” component. The ever increasing demands of automotive sector for high strength lightweight components makes flow-forming technology more challenging, promising and economically more viable. MAGNETTO WHEELS is investigating open issues regarding process reliability for manufacturing AHSS rims and fatigue resistance of flow-forming rollers, through the participation in two European research projects.

Finally, AHSS can offer opportunities for developing new concepts. MAGNETTO WHEELS designed such new concepts as “sandwich” for trucks and cars”, “full face” and “skeleton”. The ongoing engineering activity is aimed at opportunely choosing material and process parameters and geometrical optimisation. Next stage will be industrialisation with affordable costs. In this fashion, MAGNETTO WHEELS intends to use AHSS materials to demonstrate that steel wheels can meet all major market requirements of safety, lightweight, style and costs.

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