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REDUCTION OF WEIHT AND FUEL CONSUMPTION OF VEHICLES USING ADVANCED HIGH STRENGTH STEELS

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Abstract. *In recent decades the increasing competition and growing demand for light weight, high performance and crashworthiness structures in the automotive vehicle forced steel industry, automakers and the scientific community to focus more on efficient manufacturing. As a result of these, a significant increase in the usage of steel structures in automobiles was observed in last decade - especially Advanced High Strength Steels (AHSS) parts. These steels are one of the bets of the automotive industry to reduce the vehicle weight and thus reduce fuel consumption. The aim of this study was to analyze the tensile and stamping, the main mechanical properties of AHSS, since the beginning of deformation until the moment of fracture. AHSS as DP (Dual Phase), CP (Complex Phase) and TRIP (Transformation-Induced Plasticity). Were also used HSS (High Strength Steel), highlighting the HSLA (High Strength Low Alloy), micro-alloyed steels and even carbon steels. Not forgetting that the main objective is the study of AHSS, these other steels only served as a basis of comparison. Once all the properties were determined, it was possible to compare all the materials, determining the application of each steel replacing the conventional steels currently used in automobiles, in order to reduce weight and consequently the decrease in fuel consumption and pollution. Replacing the structural part of the automobiles, conventional steels by advanced high strength steels 35% more resistant, it may be possible to reduce the thickness of parts by 35%, thereby reducing total mass is 8.3% and fuel consumption of 6.6%.*

Keywords: *Mechanical Properties, Forming, AHSS, Reduction of Weight and Fuel Consumption.*

1. INTRODUCTION

The automotive industry is one of the largest markets for High Strength Steels – HSS and very important for the development of new materials and technologies. In recent decades the increasing competition and the growing demand for safer, economical and less polluting vehicles demanded of automakers, the steel industry and the scientific community at large investments of new steels research. The result of this research was the significant increase in the use of latest generation steels in vehicles.

The answer was the emergence of steels High Strength Low Alloy – HSLA containing microadições niobium, titanium and vanadium, which ferritic-pearlitic microstructure refinement and precipitation hardening capacity afforded him greater resistance mechanical. However, the consideration of these advantages was a loss of its formability these new products. Arose then, steels whose microstructure minimized losses of the formability due to higher strength levels.

The response of the global steel industry was the continued development of new types of steel sheets with increasingly appropriate to specific applications features. From the 1990s all these new steels have been merged into a single family, designated as Advanced High Strength Steel (Advanced High Strength Steels - AHSS). The increased strength level obtained with these steels leads almost inevitably to a reduction in its total elongation, ie its formability. However, the use of suitable microstructures can minimize the loss of ductility at higher strength levels.

Thus, according to Tigrinho (2011) and Behrens (2011) looking increasingly explore the influence of process parameters on forming, allowing industries meet these variables and understand better the formability of the sheet used which partly you can ensure that the produced parts will be stamping without any problems.

The issue of developing new alloys for use in the automotive industry is so latent that the last 20 years several projects are underway, involving the scientific community and major steel manufacturers in the world. The main objective of this sector has been to offer increasingly innovative materials and production methods and assembly techniques more suited to their needs, with a focus on achieving a level higher and higher security and reducing vehicle weight, in accordance with Cooman (2004) Grajcar (2005) and Chen et al. (2009).

Highlight can be given to the project entitled Ultra Light Steel Auto Body - ULSAB under the leadership of Porsche Engineering has a partnership of 35 steel companies from 18 countries. One of the benefits arising from this initiative was the introduction of High Strength Steels – HSS in automotive structures, foremost among these the Bake-Hardening steels - BH and High Strength Low Alloy Steel – HSLA. This project ended in 1998, was rated satisfactory in relation to the desired goals especially in regard to security and reduced fuel consumption, Andrade et al. (2002).

In continuation of ULSAB project, the new ULSAB-AVC program (Advanced Vehicle Concepts) proposes the establishment of new types of HSLA steels, called Advanced High Strength Steels – AHSS including Dual Phase steel – DP, Transformation-Induced Plasticity – TRIP, Complex Phase - CP, and Martensitic steels - MART, (IISI, 2002).

According Asgari et al. (2008) the main physical difference between AHSS and conventional is the microstructure. The AHSS steels are multiphase materials which may contain ferrite in the microstructure, martensite, bainite and / or retained austenite as a function of alloying elements and the processing used, Andrade et al. (2000).

The aim of this study is to analyze, through tensile testing and stamping, the main mechanical properties (tensile strength, yield strength, ultimate elongation, anisotropy and strain hardening coefficients and deformations) of Advanced High Strength Steels, since the beginning of deformation until the time of fracture. With the main goal of replacing conventional steels by Advanced High Strength Steels, to reduce the weight of vehicles and thus reduce fuel consumption and pollutant emissions.

Demonstrate by tensile testing and stamping can reduce the weight of vehicle and consequently reduce fuel consumption and pollutant emissions using Advanced High Strength Steels in of vehicle structure.

2. MATERIALS AND METHODS

Steels were used:

- AHSS – Advanced High Strength Steels: DP (Dual Phase), CP (Complex Phase) and TRIP (Transformation-Induced Plasticity);
- HSLA – High Strength Low Alloy;
- Conventional steels, such as micro alloyed and low carbon.

The main objective is the study of AHSS, these other steels served only for comparative purposes.

Through Tab. 1 you can see all analyzed steels.

Table 1. The specification and thickness of the materials analyzed.

Material	Thickness (mm)
Steel 1006	1,50
DC 06	0,70
HSLA 360/450	1,50
DP 350/600	2,16
TRIP 350/600	2,00
DP 450/780	1,96
CP 700/850	2,30
TRIP 450/780	2,00
DP 750/980	1,52

Tensile tests were performed according to NBR 8164 and NBR 6673 standards, and specimens used to form angles of 0 °, 45 ° and 90 ° with respect to the sheet rolling direction. To determine the fundamental mechanical properties, such as Tensile Strength (LR), Yield Strength (LE) and Total elongation (Al). The samples were tested to failure, being used three specimens for each rolling direction. To determine the anisotropy factor (R) and hardening coefficient (n) were also tested three samples for each rolling direction, in tests interrupted at 18% strain.

Known materials, the stamping tests were performed as tool shown in Fig. 1, to obtain FLD (Forming Limit Diagram) of DP600 steel and DC06. Using hemispherical punch with 50mm radius, with drawbead for the total locking of the specimen during deformation, applied a load on the blankholder $130x10^3$kgf without lubrication and with 10^{-3}m/s punch velocity, using three specimens for each geometry, as shown in Fig. 2.

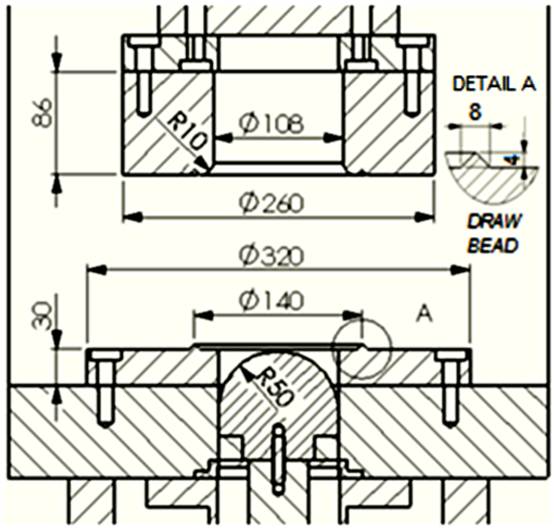

Figure 1. Hemispherical punch of radius 50 mm with drawbead in the blankholder (dimensions in mm).

The specimens, shown in Fig. 2, passed through an electrolytic process for printing mesh circles on the surface, following the sequence proposed by Schaeffer (2008). This mesh designed to measure the deformation suffered by the material after stamping.

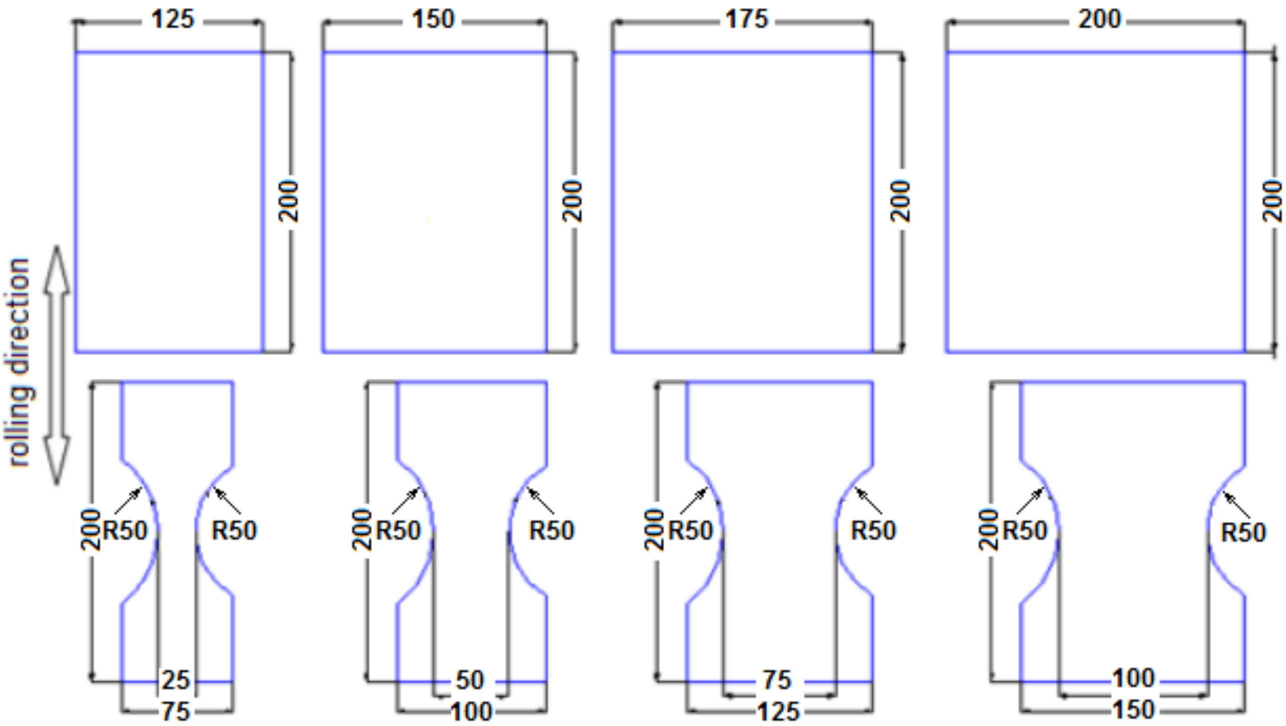

Figure 2. Test specimens used to determine the FLD.

After deformed, the specimens were measured in a flexible and transparent plastic jig, with a resolution of 0.1 mm, extracting the values of the major and minor axis of the ellipse formed by the deformation of steel.

The whole measurement process was always performed deformations opposite the fracture. From the values of the major and minor axis of each ellipse are calculated conventional strain e_1 and e_2. Then, the values are determined from the true strain ε_1 and ε_2 for determining the FLD.

3. RESULTS AND DISCUSSIONS

3.1 Tensile tests

The tensile tests, carried out on the specimens taken from formed angles of 0 °, 45 ° and 90 ° to the rolling direction of the sheet, provided information on the mechanical properties such as tensile strength (LR), yield strength (LE) and total elongation (Al). These properties characterize the steel as their limits in terms tensile strength (LR), the maximum tensile reached at the end of the elastic deformation and subsequent plastic deformation start (LE), and finally a maximum elongation (Al) steel until the moment of fracture.

Other data calculated at the end of the tensile tests were the anisotropy factor R and hardening coefficient n of the material. These two parameters characterize the material as its formability.

In addition the mechanical properties and formability parameters, the tensile test also allowed an evaluation of the material and the profile of the Tensile-Strain curve of the sheet metal.

Table 2 shows the results on the mechanical properties of the steels obtained by the tensile tests.

Table 2. Mechanical properties LE, LR and Al.

Material	Thickness (mm)	Yield strength 0.2% (MPa)	Tensile strength (MPa)	Total elongation (%)
Aço 1006	1,50	176	280	39,3
DC 06	0,70	163	327	50,2
HSLA 360/450	1,50	256	449	20,8
HSLA 420/490	1,50	415	542	17,5
DP 350/600	2,16	387	605	23,0
TRIP 350/600	2,00	381	616	32,1
DP 450/780	1,96	488	741	17,0
CP 700/850	2,30	795	850	16,7
TRIP 450/780	2,00	548	860	24,4
DP 750/980	1,52	828	934	10,4

The formability parameters R and n of the sheet, obtained by tensile tests are shown in Tab. 3. The values were obtained from the completion of three tests for each rolling direction of the sheet through which an average was calculated for each direction, as envisaged in the NBR 8164. Table 3 shows, in addition to the average values of R and n to the directions of 0º, 45º and 90º, the value of average anisotropy and average hardening.

Table 3. Formability parameters R and n.

Material	$n_{0º}$	$n_{45º}$	$n_{90º}$	n_m	$R_{0º}$	$R_{45º}$	$R_{90º}$	R_m
1006 steel	0,24	0,23	0,25	0,24	1,96	1,35	1,62	1,57
DC 06	0,27	0,26	0,26	0,27	1,96	2,12	2,68	2,36
HSLA 360/450	0,15	0,13	0,14	0,14	0,78	0,88	0,90	0,86
HSLA 420/490*	0,13	0,12	0,11	0,12	0,99	1,02	0,57	0,90
DP 350/600	0,19	0,19	0,18	0,19	0,68	1,04	1,00	0,94
TRIP 350/600	0,24	0,23	0,23	0,23	1,26	1,11	1,30	1,20
DP 450/780*	0,16	0,17	0,16	0,16	0,68	1,11	0,81	0,93
CP 700/850*	0,08	0,08	0,07	0,77	0,82	0,62	0,76	0,76
TRIP 450/780	0,26	0,25	0,25	0,25	0,85	0,90	1,09	0,94
DP 750/980**	0,08	0,08	0,08	0,08	0,88	1,04	0,93	0,97

* Obtained 10% ** Obtained 6%

The higher the values of hardening and anisotropy better will be the steel formability, Kumar (2002).

Figure 3 shows the Tensile-Strain engineering curve steels obtained by tensile test.

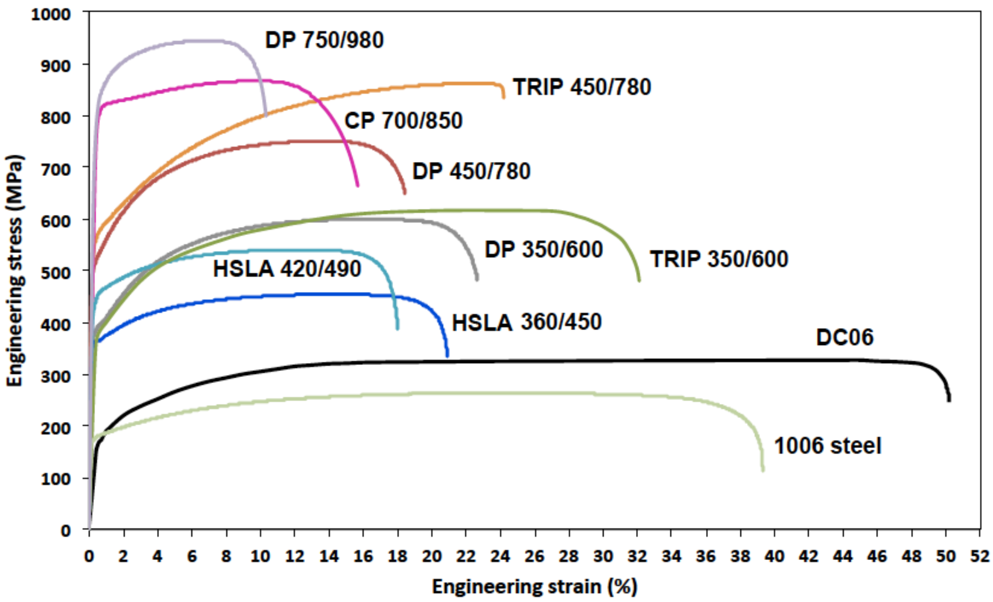

Figure 3. Uniaxial tensile curves.

Steels have an excellent combination of high strength and deformability, a result of their microstructure with lots of hardening. The high capacity of hardening ensures that these steels excellent ability to shock absorption, making these steels an interesting option for structural components and safety in vehicles.

3.2 Stamping

The stamping tests performed by the traditional method proposed by Nakazima, aimed at finalizing the characterization of steel sheet as its formability by FLD.

The test originally proposed by Nakazima uses a single punch format, hemispherical with a radius of 50mm and 100mm diameter, and a total of 18 specimens with width ranging from 25 to 200mm, all with length 200mm. From this test configuration, taking, however, a small number of specimens and without lubrication, were determined FLD, Fig. 4, the DP600 and DC06 steels. Of other steels was not obtained the CLC due to the high number of specimens and enough time to complete the survey.

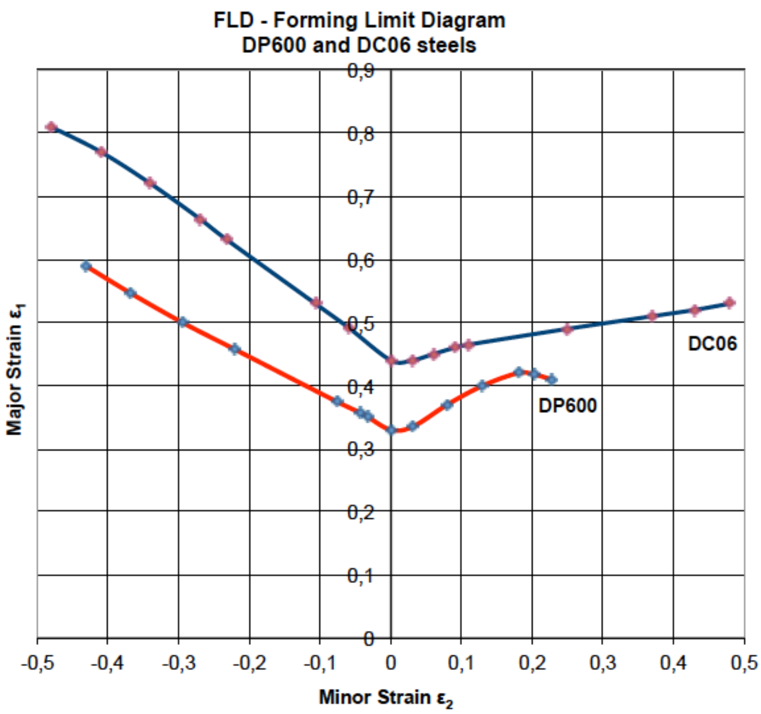

Figure 4. DP600 and DC06 FLD.

It can be seen that the deformations obtained by DC06 steel are higher than those of DP600 steel as the DC06 steel has low mechanical strength and a large elongation, so it is used in the moving parts of the vehicles, while the DP600 steel combines high strength with a some elongation and is therefore used in the structural part of the vehicles.

4. APPLICATIONS

4.1 Increased mechanical strength x mass reduction

The proposal was to replace the structural part of the vehicle's high strength low alloy steel HSLA 360/450 by advanced high strength steel DP 350/600.

Figure 5 shows the curves Tensile-Strain of the HSLA 360/450 and DP 350/600 steels.

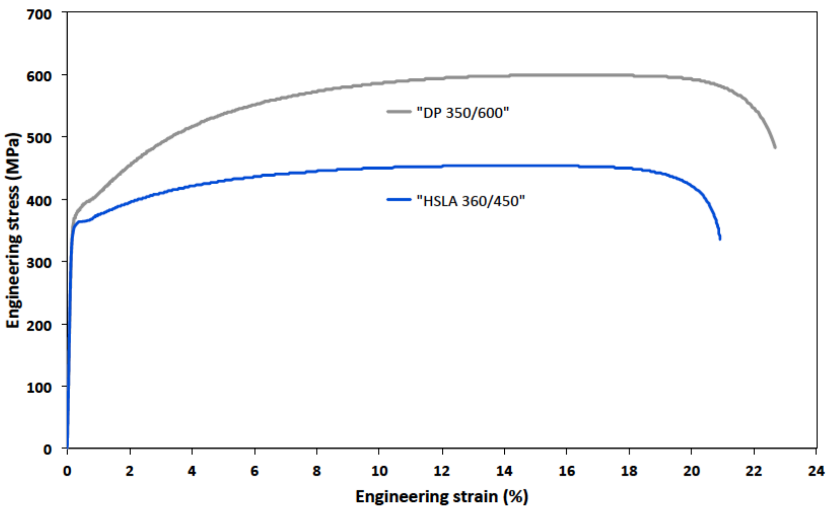

Figure 5. HSLA 360/450 and DP 350/600 Uniaxial tensile curves.

Table 4 shows the mechanical properties and formability parameters of the HSLA 360/450 and DP 350/600 steels.

Table 4. Mechanical properties and formability parameters of steels HSLA 360/450 and DP 350/600.

Material	Tensile strength (MPa)	Total elongation (%)	n_m	R_m
HSLA 360/450	449	20,8	0,14	0,86
DP 350/600	605	23,0	0,19	0,94

Replacing the steel HSLA360/450 by the DP350/600 steel, we have:
- Increased mechanical strength by 35%

Consequently:
- 35% reduction in the thickness of the parts

And the vehicle's structure:
- Mass reduction by 35%

In the vehicle Renault Sandero:
- Total mass of the vehicle: 1025 kg
  - Body (B90): 333.4 kg
    - Moving parts: 91.0 kg
    - Platform: 137.2 kg
    - Superstructure: 105.2 kg

Whereas it can be used advanced high strength steels on the platform and superstructure:
- Mass = 137.2 + 105.2 = 242.4 kg

Adopting the substitution of advanced high strength steels are more resistant 35%:
- Mass = 242.4 kg – 35% = 157.5 kg

This means a mass reduction of 85 kg in the body.
- The vehicle will pass to 1025 – 85 = 940 kg → total reduction of 8.3%.

4.2 Mass reduction x reduced consumption

Through Tab. 5 you can make a comparison between the main characteristics of Renault vehicles.

Table 5. Comparison of Renault vehicles.

Category	Model	Version	Motor	Transmission (n°)	Air Cond.	Steering	Fuel	Pollutant Emission		Mass (Approx.)	Consumption (km / l)			
				M = Manual	S = Yes N = No	P = Power	E = Ethanol	Ethanol	Gasoline	kg	Ethanol		Gasoline	
				A = Automatic		M = Mechanical	G = Gasoline	CO_2 Fossil	CO_2 Fossil		City	Road	City	Road
				MTA = Automatied		E = Electric	F = Flex	(g/km)	(g/km)					
COMPACT SUB	CLIO	Authenthique 5 p.	1.0 - 16V	M-5	N	M	F	0	87	871 - 913	9.5	10.7	14.3	15.8
COMPACT SUB	CLIO	Authenthique 5 p.	1.0 - 16V	M-5	y	M	F	0	96	872 - 913	9.1	9.6	13.1	14.3
COMPACT	SANDERO	Authenthique 5 p.	1.0 - 16V	M-5	N	M	F	0	100	1.025	8.4	9.2	12.9	13.8
COMPACT	SANDERO	Authenthique 5 p.	1.0 - 16V	M-5	y	P	F	0	105	1.025	8.1	8.6	12.4	12.8
AVERAGE	LOGAN	Authenthique 5 p.	1.0 - 16V	M-5	N	M	F	0	100	1.025	8.4	9.2	12.9	13.8
AVERAGE	LOGAN	Authenthique 5 p.	1.0 - 16V	M-5	y	P	F	0	105	1.025	8.1	8.6	12.4	12.8
GREAT	FLUENCE	Dynamique	2.0 - 16V	M-6	y	E	F	0	117	1.369	6.8	9.2	10.2	14.1
SUV	DUSTER	Dynamique 4x2	1.6 - 16V	M-5	y	P	F	0	131	1.258	6.7	7.4	10.0	10.7
SUV	DUSTER	Dynamique 4x2	2.0 - 16V	M-6	y	P	F	0	129	1.294	6.7	7.8	9.9	11.2
OFF ROAD	DUSTER	Dynamique 4x4	2.0 - 16V	M-6	y	P	F	0	143	1.353	6.1	7.2	8.9	10.2

Reference sources: Inmetro and Renault.

According to WorldAutoSteel (2009) for internal combustion engines, reduction of 10% by mass, it may result in a reduction of 6 to 8% in fuel consumption. According to calculations by the automakers, a reduction of 10% in the weight of the vehicle represents a saving of 5% to 10% in consumption. Every 100kg of weight reduction, around 400 to 900 liters of fuel can be saved throughout the entire life cycle of the vehicle, according to a JD Power office.(Brodbeck, 2014)

Through Tab. 6 you can see the vehicles of weight reduction and consequently the reduction of fuel consumption.

Using advanced high strength steels in the automotive structure:

- AHSS 35% more resistance:
  → 8.3% mass reduction
  → 6.6% reduction in fuel consumption

Renault Sandero, the consumption on the road using gasoline, will of 13,8km/l to 14,7km/l and ethanol of 13,2km/l to 13,6km/l.

Table 6. Reduction of mass x consumption reduction between Renault models using AHSS in vehicles.

Model	Version	Motor	Air Cond.	Steering	Fuel	Pollutant Emission		Mass (Aprox.)	Mass (Aprox.)	Mass (Aprox.)	Mass (Aprox.)	Weight reduction	Consumption (km / l)				Consumption (km / l) -6,6% weight → AHSS			
			Y = Yes N = No	P = Power	E = Ethanol	Ethanol	Gasoline	Body (kg)	Total (kg)	Using AHSS 35% more strength Body (kg)	AHSS Total (kg)	%	Ethanol		Gasoline		Ethanol		Gasoline	
				M = Mechanical	G = Gasoline	CO_2 Fossil	CO_2 Fossil						City	Road	City	Road	City	Road	City	Road
				E = Electric	F = Flex	(g/km)	(g/km)													
CLIO	Authenthique 5 p.	1.0 - 16V	Y	M	F	0	87	297*	871 - 913	223	818	8,3	9.5	10.7	14.3	15.8	10.1	11.4	15.2	16.8
CLIO	Authenthique 5 p.	1.0 - 16V	Y	M	F	0	96	297*	872 - 913	214	818		9.1	9.6	13.1	14.3	9.7	10.2	14.0	15.2
SANDERO	Authenthique 5 p.	1.0 - 16V	N	M	F	0	100	333.4	1.025	248.4	940		8.4	9.2	12.9	13.8	9.0	9.8	13.8	14.7
SANDERO	Authenthique 5 p.	1.0 - 16V	Y	P	F	0	105	333.4	1.025	248.4	940		8.1	8.6	12.4	12.8	8.6	9.2	13.2	13.6
LOGAN	Authenthique 5 p.	1.0 - 16V	N	M	F	0	100	342*	1.025	245	928		8.4	9.2	12.9	13.8	9.0	9.8	13.8	14.7
LOGAN	Authenthique 5 p.	1.0 - 16V	Y	P	F	0	105	342*	1.025	245	928		8.1	8.6	12.4	12.8	8.6	9.2	13.2	13.6
FLUENCE	Dynamique	2.0 - 16V	Y	E	F	0	117	456*	1.369	328	1.241		6.8	9.2	10.2	14.1	7.2	9.8	10.9	15.0
DUSTER	Dynamique 4x2	1.6 - 16V	Y	P	F	0	131	419*	1.258	301	1.140		6.7	7.4	10.0	10.7	7.1	7.9	10.7	11.4
DUSTER	Dynamique 4x2	2.0 - 16V	Y	P	F	0	129	431*	1.294	310	1.173		6.7	7.8	9.9	11.2	7.1	8.3	10.6	11.9
DUSTER	Dynamique 4x4	2.0 - 16V	Y	P	F	0	143	462*	1.353	324	1.215		6.1	7.2	8.9	10.2	6.5	7.7	9.5	10.9

* Approximate values

4.3 Using AHSS x increase vehicle safety

One thing is certain: accidents happen. One way of avoiding serious injury is to manufacture vehicles with advanced high strength steels.

Figure 6 shows the vehicle frontal crash test.

Figure 6. Frontal crash test. (WorldAutoSteel, 2009)

Through Fig. 7 it can be observed deformations between two steel subjected to the same stress.

Figure 7. Comparison of deformation of HC380LA and DP600 steels. (Corus, 2009)

You can see that the microalloyed steel HC380LA had a much larger deformation compared to advanced high strength steel DP600.

Os aços avançados de alta resistência combinam alta resistência mecânica e capacidade de deformação (grande capacidade de encruamento), por isso são utilizados em componentes estruturais e de segurança dos automóveis.

The advanced high strength steels combine high strength and deformability (high capacity hardening), are therefore used for structural components and safety in vehicles

5. CONCLUSION

Through the tensile tests and stamping was possible to prove that advanced high strength steels combine high strength with elongation as compared to other steels used in structural part of the vehicles.

Using advanced high strength steels to replace conventional steels in vehicles, we have:

- decrease in the thickness of the sheets and therefore:
- mass reduction of the vehicles;
- lower power consumption;
- lower emissions of pollutants and
- increase the safety of vehicles.

In the model Renault Sandero using advanced high strength steels 35% more resistance in the structure and platform, you can reduce 85kg in the mass of the vehicle, from 1025kg to 940kg, this means a reduction in fuel consumption of 6.6% thereby reduces the emission of pollutants, not to mention the increase in vehicle safety.

From the results presented in this study, the technological contribution we missed, is a greater understanding and advantages in the use of advanced high strength steels to replace conventional steels currently used in vehicles.

6. ACKNOWLEDGEMENTS

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