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Development of Pre-Coated Boron Steel for Applications on PSA Peugeot Citroën and RENAULT Bodies in White

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ABSTRACT

The automotive industry have to face with its will to increase the safety of the passengers and the necessity to reduce the pollutant emissions. Besides, the customers expect more and more high vehicle quality and especially as far as corrosion is concerned.

The development of the pre-coated boron steel associated with the hot stamping allows PSA Peugeot Citroën and RENAULT to lighten their parts significantly and fulfill the automotive corrosion requirements.

The benefit in crash resistance has been obtained by the increase of the mechanical properties after heat treatment. After a complete austenitisation in a 930°C furnace, the blanks are stamped and quenched in one step in a water cooled tool. This process allows to obtain :

YS > 950 MPa

TS > 1300 MPa.

INTRODUCTION

The reinforcement of regulations in terms of pollution (CAFE 2008 CO_2 emission under 140 g/km) and the increase of equipments induce that the automotive industry has a critical need for weight reduction solutions for car bodies. Moreover, the crash resistance objectives are more and more severe to improve the car safety and lead the manufacturers to reinforce the bodies in white. Then, the lengthening of anti-corrosion guarantees requires a two sides pre-coated steel supply.

This challenge is achieved through the use of steels having the highest possible mechanical properties, meaning, however, a decrease of formability.

In order to solve this problem, it was necessary to make a breakthrough with respect to the continuous process of increasing mechanical characteristics. For this, the forming and properties-of-use functions have been considered separately in the development of the USIBOR steel. The as-delivered USIBOR steel allows easy forming and, after heat treatment, presents high mechanical characteristics and corrosion resistance compatible with the new guarantees given by the manufacturers to their customers.

In order to meet these requirements, a working group was created between USINOR, PSA Peugeot Citroën and RENAULT with the objective to develop a pre-coated version of the USIBOR steel.

PRE-COATED USIBOR 1500

1/ POSITION IN THE RANGE

Pre-coated USIBOR 1500 has been developed to reply to the weight reduction needs for structural and reinforcement parts of automobiles (fig. 1), and the lengthening of the anti-corrosion guarantees.

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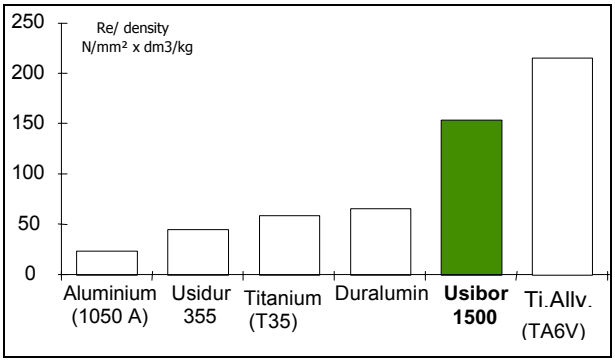

Figure 1 : Weight reduction potential of USIBOR 1500 compared to other materials according to their yield strength.

This internationally patented steel, with its high hot forming possibilities, make it possible, after heat treatment, to obtain very high mechanical characteristics, with exceptional impact resistance.

The heat treatment is carried out after forming in order to obtain a high tensile strength level.

Mechanical characteristics, before and after heat treatment are shown in figure 2.

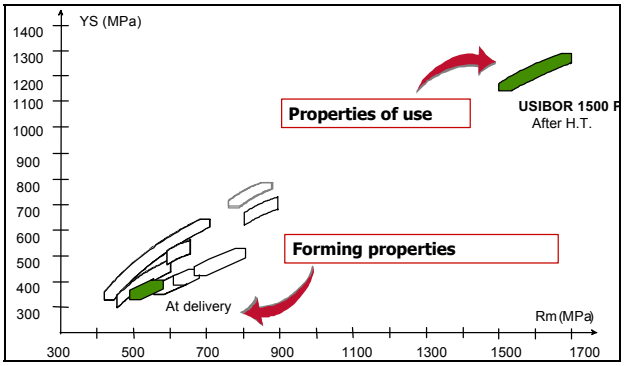

Figure 2 : Mechanical characteristics, before and after heat treatment.

2/ METALLURGICAL PROCESS

2-1 Chemical analysis and coating.

USIBOR 1500 is a carbon/manganese steel micro-alloyed with boron.

	C	Mn	Si	S	Cr	Al	B	Ti
Mini	200	1100	150		150	20	2	20
Maxi	250	1350	350	8	300	60	4	50

Chemical analysis in thousandths of a %.

In order to protect the metal from oxidation and decarburization during heat treatment, and to increase corrosion resistance after painting, an aluminium based pre-coating is applied with a hot dipped process, the thickness of which is usually between 23µm and 32µm per face.

2-2 Effects of additive elements and rolling.

The addition of carbon, manganese, and chrome give good quenchability and the slight addition of boron increases this latter considerably. The boron, in effect, enables the ferritic zone to be shifted towards low cooling speeds thus ensuring good quenchability of parts during heat treatment (critical quenching speed : 27°C/s).

The titanium acts as a nitrogen scavenger thus protecting the boron. Sulphides are globularised with a SiCa treatment.

The thermo-mechanical process applied during the manufacture of hot and cold re-rolled products, enables a homogeneous structure, guaranteeing good formability and reproducible mechanical characteristics, to be obtained before and after heat treatment.

2-3 Microstructures of steel and layer at delivery

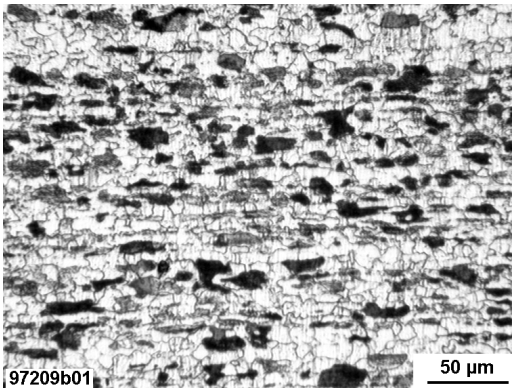

Figure 3 : Typical HSM ferrite-pearlite microstructure.

The homogeneous distribution of pearlite and an equiaxed grained, ferritic matrix may be noted.

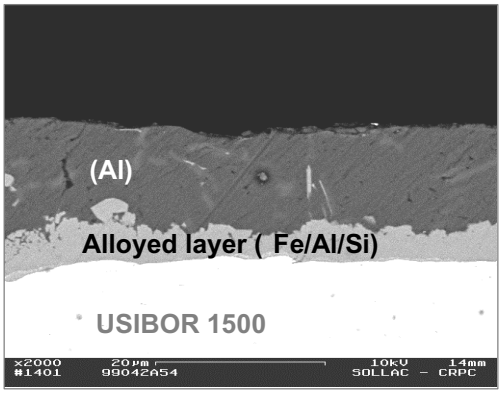

Figure 4 : Typical microstructure of coating section by BSE on an SEM.

The coating is composed of an alloyed layer in contact with the substrate on which a layer, composed principally of aluminium, develops.

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3/ INFLUENCE OF THE HEAT TREATMENT

3-1 Typical mechanical properties

Blanks are heated to around 900°C for a few minutes.

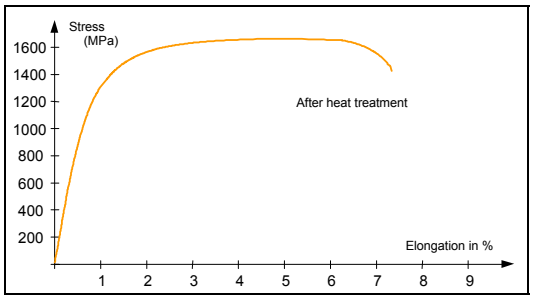

Figure 5 : Typical tensile curve after heat treatment.Thickness 1mm.

After heat treatment, USIBOR 1500 still shows a high capacity for consolidation. The typical tensile results on as-delivered metal and on quenched test pieces are shown below :

	YS (MPa)	TS (MPa)	E% (20x80)
At delivery	400	600	20
After hot forming	1060	1500	5

The ratio YS/TS is between 0,6 and 0,7 at delivery depending on size and between 0,65 and 0,75 after quenching in the die.

3-2 Microstructures of steel and Al-Si coating

Heating the pre-coated USIBOR 1500 at the required temperature creates an alloying reaction by iron diffusion from the steel to the coating. The result is the formation of a multiphase Fe-Al-Si layer. The two main consequences is an increasing of the layer hardness (figure 6) and the layer thickness around 20 µm.

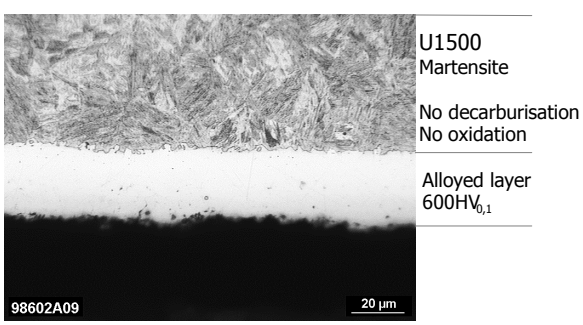

Figure 6 : Typical microstructure of coating section by optical microscope with 4% Nital etch.

Figure 6 shows the totally martensitic structure without the presence, of surface decarburization or oxidation. It may be noted that the very hard alloyed layer, is strongly adhered to the substrate.

One of the advantages of the coating is to be an obstacle to the carbon diffusion and so, allows an easy control of the furnace atmosphere.

4/ CHARACTERISTICS OF USE

4-1 Heat treatment.

4-1-1 Jominy curve

Up to 7 mm in depth, maximum hardness is retained, guaranteeing quenching throughout the metal, whatever the thickness supplied.

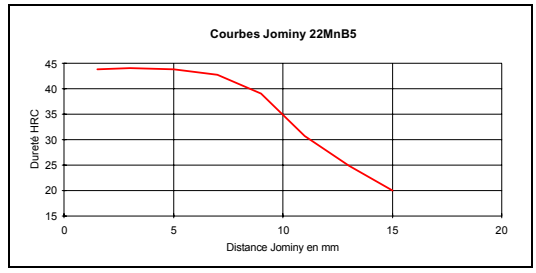

Figure 7 : Jominy Curve.

4-1-2 Austenitisation

The point Ac_3 is at 850°C, for a heating speed of 5°C/s. The structure of a tensile test sample, austenitised for 5 min at 850°c and water quenched, is totally martensitic. At 840°C some ferrite islands persist. Considering the homogeneity of the initial structure, these islands are evenly distributed.

The point Ac_1 is at 750°C, Ms is at 400°C.

For austenitisation at 900°C, the linear dilatation of the metal is 1,13% at this temperature.

4-1-3 Recommendations

The following recommendations enable the complete alloying of the coating ensuring good corrosion resistance.

For 1,2 mm thick blanks, heated in an electric or gas furnace. The furnace dwell time (from door opening to door opening) must be greater than the following :

Temperature	880°C	900°C	950°C
Mini time	5 min	4 min	3 min

These times must be adapted to the substrate thickness.

4-1-4 CCT Diagram

The CCT diagram was made under the following conditions :

Austenitisation : at 900°C for 5 min

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Temperature increase rate: 15°C/s

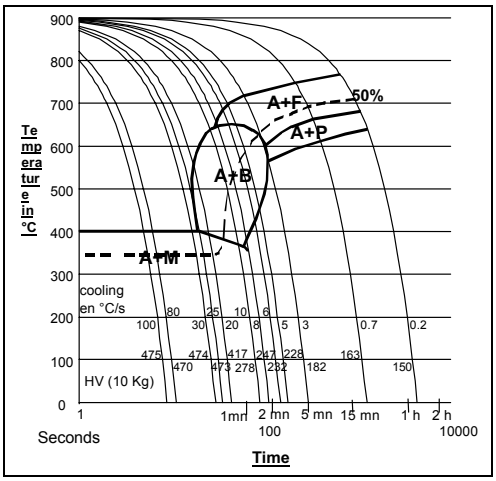

Figure 8 : CCT curve for USIBOR 1500.

The critical quenching speed enabling a completely martensitic structure, under these conditions, is 27°C/s.

4-1-5 The influence of annealing

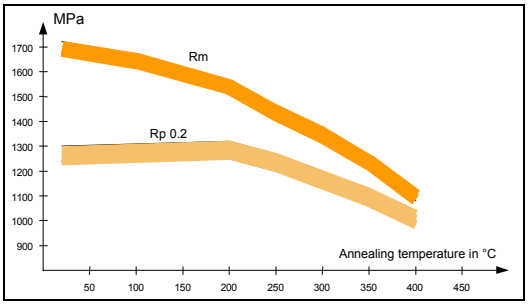

Figure 9 : Influence of annealing temperature.

The water quenching of the test pieces was carried out after austenitisation at 950°C for 5 min. The dwell time for the different coatings was one hour. Elongation at rupture varied little with annealing temperature and was between 5 and 7% (for ISO 20x80 test pieces 1 mm thick).

It is interesting to note that heat treatment due to paint baking (bake hardening) brings about an increase in yield strength of 100 MPa.

4-2 Weldability

4-2-1 Spot welding.

The mean carbon equivalent is 0.50%.

$$CE=(\%C)+(\%Mn+\%Si)/6+(\%Cr+\%Mo+\%V)/5+(\%Cu+\%Ni)/15$$

When quenched strip is spot welded, the weldability range, determined according to standard NFA 87-001, is higher than 2kA whether by homogeneous welding or on an XES G10/10 (HDG DDQ, 140g/m² BS). The cross tensile strength is conform to standards.

Electrode test life give excellent results, being greater than 5000 spots compared to 700 spots typically for galvanised strip. Even in a triple thickness configuration, electrode life is 2 to 3 times longer compared to galvanised XES.

4-2-2 MAG Weldability

MAG welding gives no particular difficulties. Concerning mechanical resistance, it is recommended to use wire with C>0.1%.

4-3 Impact resistance.

Most present applications concern anti-intrusion parts (passenger compartment or engine), for example door reinforcements and bumper beams.

These trials are carried out using a catapult (Fig. 10) with a test piece as shown in figure 11.

The 300kg impactor is propelled at 29km/h corresponding to an energy level of 10 kJ.

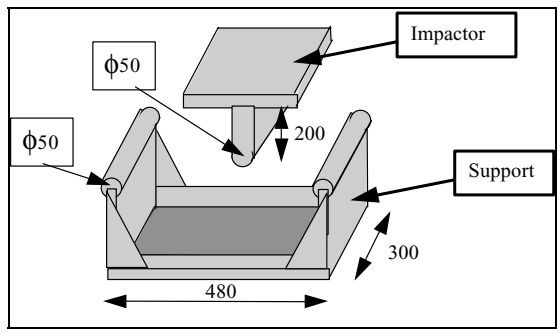

Figure 10 : Bending impact test assembly.

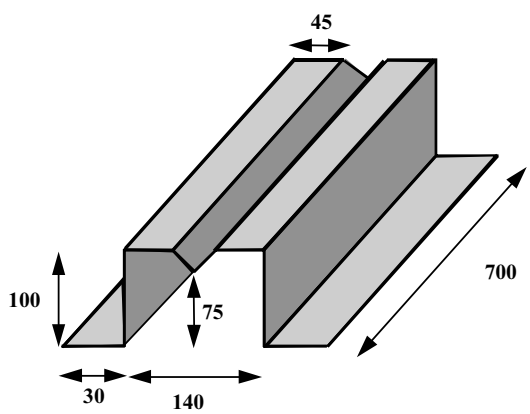

Figure 11 : Schema of the test piece for the three-point bending impact test.

Figure 12 : Photo of a typical test piece after a dynamic, three- points bending impact test.

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In terms of ultimate force before structural collapse, USIBOR 1500 permits thickness reduction, and thus considerable weight saving, compared to the use of HLE steels. What is more, the behaviour is reproducible in terms of force peak, absorbed energy and rupture mode.

Even for high speed crashes, all the fractured areas present a ductile aspect.

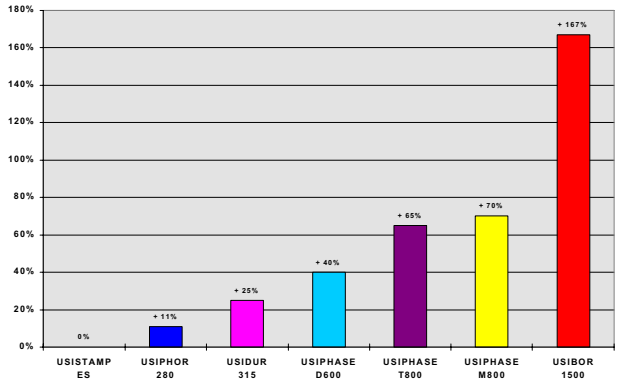

Figure 13 : Ultimate force, 3 points bending.

4-4 Aptitude for coating of die quenched parts and blanks.

4-4-1 The corrosion resistance of non-painted parts with no temporary protection.

Given the iron content of the coating after alloying and if the part is not painted, red rust may appear (RR), if the part is exposed to a very humid atmosphere. However, if watermarks appear on un-coated strip, this is not the case with USIBOR. The first traces of RR appear after 10 cycles in a humidity cabinet (DIN 50 017 cycles FKW).

For 3 months' exposure to marine atmosphere in an open hall, there was no appearance of RR.

The loss of mass, after 1000h exposure to salt spray was less than 100g/m² whereas for a galvanised steel, it was 140 g/m² and more than 1200 g/m² for an un-coated reference steel.

The presence of an alloyed coating renders the application of temporary protection on parts stored under normal conditions, unnecessary.

4-4-2 Aptitude to surface treatment (ST) and to cataphoresis.

The phosphatisation bath used is of the Henkel Granodine 958 (Trication) type.

The surface is not phosphated but remains unchanged during its passage through the bath. It does not pollute the bath with dissolved Al.

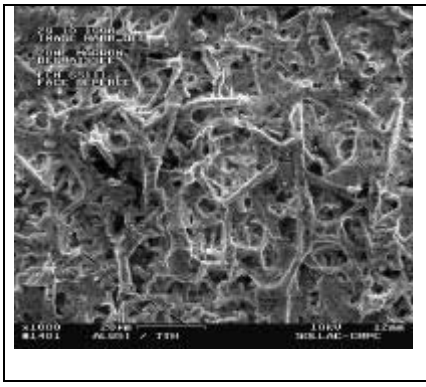

Figure 14 : SEM image of surface roughness after complete alloying

The high roughness level of the alloyed layer results in the cataphoresis having exceptional adherence. Covering is total, from 8µm of paint thickness.

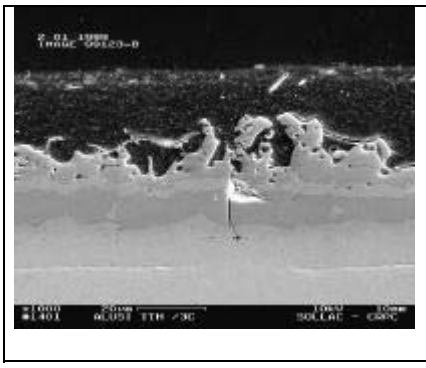

Figure 15 : Section of alloyed and cataphoresis layer by SEM in BSE mode

4-4-3 Corrosion resistance of parts painted by cataphoresis .

The product used for E-coat is of the type, PPG 742/762.

After Renault 3C type corrosion test (9 weeks), average delamination was 2 mm. The depth attained was less than 80µm compared to the reference steel with a depth of 150 and 250µm.

There was also a good response to the VICT test (VOLVO/PSA lasting 12 weeks) with very limited delamination, ~0.5 mm for an admissible maximum of 3 mm. Better protection may be noted on the edges, compared to the reference steel but less than those seen on galvanised steel.

Salt spray tests show that, after 1000h exposure, the peeling is still less than 3 mm.

Scab-Tests (3, weekly NaCl sprayings) carried out at Fos/Mer in a marine and industrial atmosphere show that, after 6 months' exposure, the cataphoresis' peeling is still less than 2 mm with depths attained less than 25µm (Fig. 16). The same tests on a reference steel and a galvanised steel show delamination of from 5 to 7 mm and from 2 to 5 mm respectively with depths of from 100 to 200 µm and from 25 à 70µm.

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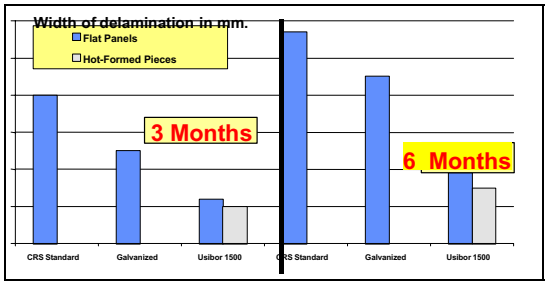

Figure 16 : Measurements of delamination width after 3 and 6 months' Scab-testing carried out at Fos/Mer.

Figure 17 : Photo of a hot-formed part after 6 months' Scab-testing carried out at Fos/Mer.

The galvanic corrosion behaviour was also evaluated through accelerated corrosion testing on spot welded test pieces bringing galvanized metal into contact with USIBOR. Results show that the risk of galvanic corrosion between the zinc and the alloyed layer of USIBOR were negligible, if not zero.

The behaviour of parts is equally excellent regarding the wet adherence in polluted water at 40°C considering the fact that after 21 days the adherence of the E-coat is remarkable.

Finally, stone chipping resistance was studied on parts, upon which a complete set of paint layers was applied on surface treated and E-coated surfaces. Results were identical to those for galvanized steel.

Then, whatever the test carried out on the painted part, the inner surface corrosion resistance is excellent. For edges, complementary protection (wax, mastic etc.) is necessary, applied as necessary, depending on the particular parts concerned.

The good capacity for corrosion resistance of the material is due to the thickness increasing of the layer after heat treatment. The corrosion studies on different coating thickness lead to the conclusion that the minimum thickness to answer the corrosion requirements of RENAULT and PSA Peugeot Citroën is 23 µm before heat treatment.

HOT STAMPING PROCESS

The hot stamping process is composed by different steps : a blanking press, a furnace, a roboted arm to transfer the hot blanks in the press and a tool with a water cooling system to stamp and quench in the same step.

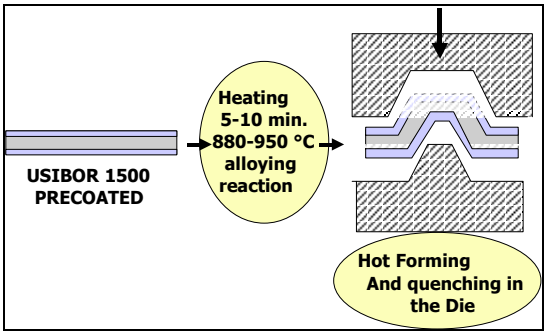

Figure 18 : Schema of the process principle for hot forming.

1) THE FURNACE

The blank is heated at 930°C for several minutes. At such temperature the steel is very ductile and is easily formed into complex shapes without springback.

The heating time depends on the thickness of the blanks and has to ensure the good alloying of the Al-Si coating. Even if the coating is an obstacle to the diffusion of carbon, it is necessary to control the furnace atmosphere to limit the decarburization on the trimming edge.

Besides, the coating avoids the appearance of an oxide layer on the parts and so allows to eliminate the descaling operation in the process. This result is very important for the automotive industry which is more and more concerned by the environment protection.

Figure 19 : blank just before the tool closing.

2) THE BLANK TRANSFER

The transfer operation must be realized as quickly as possible to assure the required mechanical properties on the part according to the CCT diagram. If the blank temperature falls below 780°C, the microstructure will present bainitic or ferritic areas.

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3) THE PRESS AND TOOL

The hot blank is placed by the roboted arm in the tool which is water cooled to room temperature. The tools remain closed for approximately 15 seconds by the hydraulic press. Then, the part is extracted from the tool at a temperature around 80°C to guarantee a good geometry after the final air cooling. So, the production rate allows to realize 2 or 3 stamps per minute.

The pre-coated USIBOR 1500, optimized for the stability of its quenchability, is transformed, at the end of forming, into pure martensite thus giving very high mechanical characteristics to then finished part : YS~1000MPa, TS~1500MPa.

The chemical composition and microstructure of USIBOR 1500 are optimized to obtain a homogeneous microstructure for a wide range of cooling speeds and so, very regular mechanical characteristics.

3) THE CUTTING AND PIERCING

The cutting and piercing tools are used with conventional mechanical press. However, the high hardness of the steel and the coating after heat treatment, leads to use specific gap and adapted material for cutting dies.

APPLICATION IN THE CITROËN C5 SUBFRAME

According to the reinforcement of crash resistance regulation and more severe EuroNcap specifications, intrusions have to be limited in the passenger compartment in high speed frontal crash (64 km/h and 40% overlap).

USIBOR1500 has been chosen by the C5 project team to improve the crash resistance of A frames without increasing the weight of the body in white. Thanks to the high level of yield strength after hot stamping (about 950 MPa), more load can come through the C5 A frame without plastic deformations during high speed frontal crash.

Citroën C5 A frame reinforcement is 1,17 mm thick and 1000 mm length; Two A frame reinforcements are stamped in one stamp from a single blank; right and left parts are cut after hot stamping.

figure 20a: Blank just before stamping

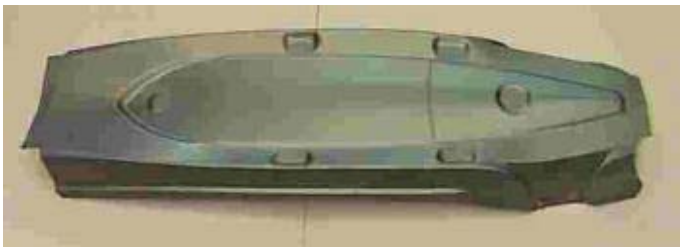

Figure 20b: Blank just after quenching

The use of a coating is necessary in this area due to the situation of the part in the body in white. Indeed, this area is hardly requested by the water flow from the roof inside the frame. Thanks to the AlSi pre coated boron steel, corrosion protection is increased and in accordance with PSA Peugeot Citroën specifications.

About welding operations, the main concern was linked to the spread of the coating thickness on the stamped part. The evolution of this thickness (about 15 microns) is linked to the initial variation of coating thickness (about 9 microns) on the blanks and to the evolution of process parameters (such as the austenisation time). Assembly trials were carried out to verify, for the maximum acceptable range of thickness, the steadiness of the industrial assembly process. The quality of the welding electric points was checked and are in accordance with our specifications.

The use of a precoated USIBOR1500 hot stamped A frame reinforcement in the subframe means high geometric tolerances on the parts in accordance with PSA specifications. For example, +/- 0,5 mm are reached on the shape and on the trimmings of the part.

Figure 21 : C5 A frame reinforcement

Then, the development of precoated hot stamped A frame reinforcements permits to fulfill EuroNcap four stars level and corrosion protection. It allows also to reduce weight of about 1,4 kg on the C5 body in white compared with a conventional 300 MPa high strength steel. Besides, it's a first world application in the subframe for very high production rate of stamped parts.

APPLICATION IN THE RENAULT LAGUNA II FRONT BUMPER BEAM

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absorb impact and/or protect the vehicle against intrusion in case of several crash scenari. For the LAGUNA II, RENAULT adds another functional criteria concerning the new corrosion guarantee. Besides, the front bumper beam support the recovery eye fixing.

For urban crash at 15 km/h, the front bumper beam has to limit the intrusion in the vehicle in order to minimize the cost of repairing and must assure the good rails members behaviour in high speed frontal crashes (64 km/h - 40% overlap).

To design this part, RENAULT has chosen to use the couple USIBOR 1500 / hot stamping to combine the use of an UHSS, i.e. maximum weight reduction, and a complex geometry, i.e. length 1400 mm and stamping depth 70 mm.

In comparison with the classic HSLA solution, the high yield strength (≥ 1000 MPa after heat treatment) allows the project team to divide the thickness of the part approximately by two. The front bumper beam is 2 mm thick.

The blank is heated at 930°C during several minutes. Cutting and piercing operations are realized after hot stamping. Different controls have been made on parts after hot stamping, to check the metallurgical and geometric quality : minimum coating thickness to ensure a good corrosion behaviour, mechanical properties reproducibility, maximum thinning of the steel.

Figure 22 : LAGUNA II front bumper beam before and after cutting

To meet RENAULT corrosion requirements, the E-coat has to lead to a thick cover layer on the edges. The result is a 10 µm minimum thickness layer compared to 1 to 3 µm with a standard E-coat.

Even if the average elongation is around 5 to 6 % on part, all the crash resistance tests are positive according to the RENAULT specification and notably, for the urban crash where the important stiffness of the part limits significantly the crash intrusion.

figure 23 : Front bumper beam of the LAGUNA II after urban crash

Different laboratory accelerated corrosion tests show a very good behaviour of the front bumper beam. Thanks to the use of the couple pre-coated steel and specific E-coat, there are no red rust and no perforation after an equivalent of « 12 years ».

This technical solution is considered as a success :

1- The LAGUNA II has a very good crash behaviour in each scenari with a significantly weight reduction of the front bumper beam : first vehicle to obtain ★★★★★ EuroNcap.

2- The corrosion behaviour of this part is excellent (12 years without red rust and perforation)

3- RENAULT takes part in environment protection with the use of an unleaded E-coat and the Al-Si pre-coated which allows the acid descaling cancellation.

figure 24 : EuroNcap front crash of the laguna II

CONCLUSION

The main advantages of USIBOR 1500 are to combine an easy hot formability without springback and a high level of mechanical properties after quenching (YS > 950 MPa, TS > 1300 MPa and E% > 4,5 %).

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The corrosion behaviour of the pre-coating allows to use this steel on the body in white even with the new corrosion criterias. Besides, it allows to cancel the descaling operation after heat treatment (no oxide layer) and it avoids the decarburization.

With the use of pre-coated boron steel and hot stamping, PSA PEUGEOT CITROEN and RENAULT lighten their bodies in white and increase the protection of the passengers.

REFERENCES

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