Galvanized high strength bainitic steels

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Summary

A cold rolled complex phase steel (CR780CP) and a hot rolled bainitic steel (HR900B) both with improved hole expansion ratios are compared to a conventional cold rolled dual phase steel (CR780DP) that has not been optimized with respect to formability. All of the steels are hot dip galvanized, the sheet thicknesses are approximately 1.8 mm and the tensile strength levels are within the range of 800 to 900 MPa.
The essential difference in the properties is based on the microstructure that not only accounts for the variance in yield ratio of 62% (CR780DP), 78% (CR780CP) and 97% (HR900B). It is also responsible for several property aspects that particularly benefit from the high amount of bainite that characterizes CR780CP and HR900B. It is shown that the investigated “modern” hot dip galvanized CR780CP and HR900B steels have 2.5 times higher hole expansion ratios than first generation CR780DP and 30% better bending performance. CR780CP and HR900B show similar performance in cup drawing and stamping trials thereby demonstrating the potential of multiphase steels regarding the design of microstructure. Thus, facing specific problems that may not be solved by substituting a “first generation” DP steel for an advanced DP steel, it is worth to consider the application of CP- and bainitic steels.

Keywords

Complex phase steel, bainitic steel, dual phase steel, hot dip galvanized, high strength steel, hole expansion ratio, stretch flange ability, deep drawing

Introduction

In regard to the CO2-debate, light weight construction in automobile industry is one major driving force in the development of multiphase steels. A way to vehicle’s weight reduction is to diminish the component thicknesses by substitution of existing materials for grades of higher strength.
Concerning the mechanical properties taken from the tensile test, it is a common tendency that uniaxial elongation is reduced with increasing strength. Certainly, other (multiaxial) aspects of formability are not affected in such a distinct way, thus offering the chance of increasing both, strength and formability.
One of the aspects is the stretch flangeability, i.e. the material’s ability to resist failure within a punched edge when stretched severely. The technical parameter is defined as hole expansion ratio (HER) obtained from the hole expanding test (HET). The HER is a crucial parameter that might be regarded with similar importance as the deep drawing potential when assessing material for components with flanges or complex forming near edges. However, as the method of testing and details in conduction may have a severe impact on the results, care has to be

taken when comparing values from different sources in order to obtain a reliable material characteristic [1, 2, 3, 4].
Bainitic and complex phase (CP) steels (that predominantly consist of bainite) play an interesting role in the context of strength and ductility as they provide an advantageous mixture of properties due to their favourable microstructure with reduced affinity to local damage [5]. In this paper, a cold rolled CP steel and a hot rolled bainitic steel both with improved hole expansion ratios are compared to a conventional dual phase (DP). All of the steels are hot dip galvanized. The intention is to show the specific properties coming along with bainitic structures that may even compensate for a lack of total elongation when compared to conventional DP steels. As the galvanized steels are increasingly demanded in high strength automotive parts with improved corrosion protection, the focus of this contribution is on hot dip galvanized strip in the strength class from 800 to 900 MPa.

Investigated steels

The investigated steels are processed at Salzgitter steel company within different optimization projects. The first steel in Table 1 denoted “CR780DP” can be regarded as reference material in this investigation. It represents a conventional cold rolled and hot dip galvanized DP steel as defined in DIN EN 10346 or VDA 239 containing 0.15 wt% carbon and other elements as given in Table 2. No particular optimization was applied on this steel regarding formability and thus denoted “first generation” in the table. The microstructure presented in Fig. 1 consists basically of similar proportion ferrite and martensite in banded formation. The allover grain size is ASTM 13-14.

Table 1: Main characteristics of investigated steels

name	thickness	type		process		VDA / DIN
CR780DP	1.75 mm	dual phase	“first generation”	cold rolled	hot dip galvanized	CR440Y780T-DP HCT780X
CR780CP	1.8 mm	complex phase	new concept			CR570Y780T-CP HCT780C
HR900B	1.8 mm	bainitic		hot rolled		- -

Table 2: Nominal composition of investigated steels

Steel	C [wt%]	Mn [wt%]	Si [wt%]	Cr+Mo [wt%]	Nb+Ti+V [wt%]
CR780DP	0.15	2.0	0.25	0.35	-
CR780CP	0.15	2.0	0.25	0.35	>0.01
HR900B	0.1	2.0	0.45	0.15	>0.1

The composition of the cold rolled complex phase steel “CR780CP“ mainly differs in the addition of microalloying elements and in the processing route. Owing the defined quenching before the cold rolled strip enters the zinc pot in the continuous galvanizing line the microstructure contains predominantly bainite with small amounts of ferrite and tempered martensite. As the micrographs in Fig. 1 show, the

banding is far less pronounced than in CR780DP, the grain size is complicated to define; however, it appears smaller than in CR780DP. CR780CP is designed for expanded formability and edge crack resistance, i.e. high HER values and also satisfies the specifications of both DIN EN 10346 and VDA 239.
The steel denoted as "HR900B" is a hot rolled and subsequently hot dip galvanized steel containing half of the carbon compared to the cold rolled steels. The strength level is realized by use of considerably higher amount of microalloying elements. The microstructure is characterized by a bainitic matrix that may contain a minor percentage of ferrite and small carbides that are barely visible in the optical microscope. Banding does hardly occur.

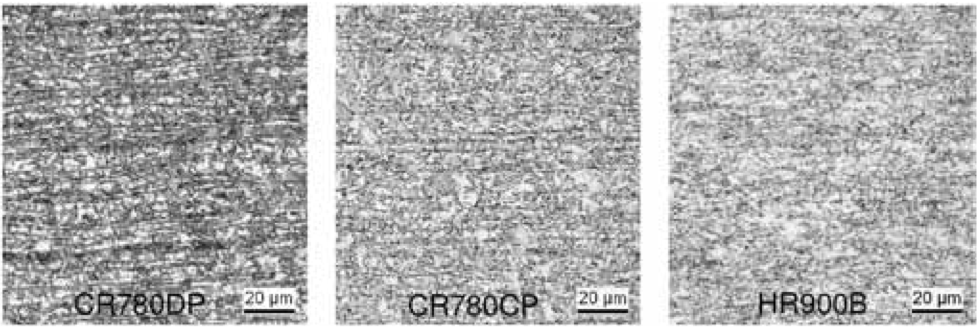

Fig. 1: Microstrucure of investigated steels, Nital etching, x 500, from left to right: CR780DP, CR780CP, HR900B

Experimental conditions

The tensile test was performed consistent with the established practices in steel industry (DIN EN ISO 6892). According to the sample thickness the gauge length was 80 mm.
For HET according to ISO 16630 square samples with an edge length of 100 mm with a central hole of 10 mm diameter were used. All samples were punched consecutively using the same die in order to minimize any tool influences. The die clearance was set to 12±2%. The hole was expanded using a 60° conical punch. As soon as a crack through the total sheet thickness was visibly detected the expanding process was stopped immediately. The HER is given by the ratio of the increase in the hole diameter to the original hole size [6].
An alternative edge cracking test called "hole expanding test with Nakajima punch" is carried out based on the setup for the determination of the forming limit curve. At first a hole with a diameter of 20 mm was punched into the test piece with a quadratic area of 190 x 190 mm² using a clearance of 12 %. Afterwards the hole was expanded by the hemispheric Nakajima punch. The crack was detected both visually by the operator and by an optical measurement device (ARAMIS). Applying an evaluation macro to the ARAMIS video sequence, which contains certain crack criteria, the crack point in time as well as the hole expansion ratio were automatically detected and evaluated, respectively [7].
The three point bending test was performed in accordance to VDA 238-100. In each case five samples with a quadratic size of 60 x 60 mm² were bent parallel and

perpendicular to the direction of rolling using an upper anvil with a radius of 0.4 mm.
The forming limit curves were determined according to ISO 12004 using the hemispheric Nakajima punch and the intersection line evaluation method. In order to analyze the forming behavior at plain strain conditions the investigation was limited to the bottom dead centers.
The cup drawing test was conducted using a punch with a diameter of 33 mm. To minimize tribological differences caused by different surfaces, Teflon film was applied both on the upper and lower surface of the specimen. Different drawing ratios were investigated starting with 1.67.
A stylized B-pillar component was employed to compare the forming behavior of the different materials using a real part geometry. In order to minimize the friction influence Teflon was used again. A constant depth of draw as well punch speed was applied. All blanks were identical in shape.

Experimental results and discussion

As presented in Fig. 2, the tensile strength level of CR780DP and CR780CP is approximately 800 MPa, independent of the testing direction. HR900B shows tensile strength values of 885 MPa and 935 MPa in longitudinal and transversal direction, respectively. The yield strength values are significantly different and thus result in average yield ratios of 62% (CR780DP), 78% (CR780CP) and 97% (HR900B). The increase in yield strength is caused by the lack of ductile ferrite that allows yielding already at a comparably early stage. With increasing yield strength the average total elongation decreases from 18% (CR780DP) to 16% (CR780CP) and 14% (HR900B). The differences in uniform elongation, however, demonstrates the strain hardening character of DP as it decreases from 13.5% (CR780DP) in almost one step to 9.5% (CR780CP) and 9.0% (HR900B).

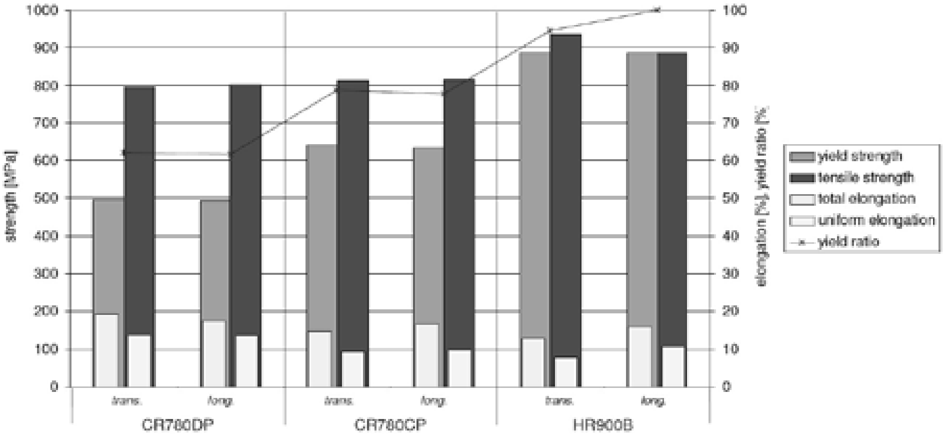

Fig. 2: Results from tensile test for CR780DP, CR780CP and HR900B

The different HET experimental setups deliver different values for HER owing the punch geometries and resulting stress state [7, 8]. Thus, in Fig. 3 the HER values are scaled to 100% for CR780DP.

The differences in hole expansion between the DP-steel on one side and the CP- and bainitic steels on the other side are the factor 2.5 to 3.5 depending on the experimental procedure. The hole expansion levels of the CP- and bainitic steel are the same, only the deviation in HER of the hot rolled HR900B is about two times of the cold rolled CR780CP related to the same number of investigated samples, respectively.
The HER levels originate from the microstructure as presented in various sources, e.g. [5] and [9]. The dominant damage cause in HET is local damage due to restricted strain at the edge in difference to tensile test that allows strain hardening within the complete gauge length. Bainitic structures are less sensitive to local damage, e.g. micro void nucleation at phase boundaries and subsequent local failure.
Slight influence of the test procedure can be observed in Fig. 3. Obviously the differences in hole expansion potential of both microstructures are more pronounced using the Nakajima tool. The use of optical strain analysis allows the detection of early stages of cracks and thus results in lower values and reduced deviation, however, shows the same tendency.
Customer stretch flange trials of CR780CP in comparison to a conventional dual phase steels are presented by the bottom photographs in Fig. 3. Though a flat punch is used and other experimental conditions differ, again, the higher performance regarding edge crack resistance in the complex phase structure is observed.

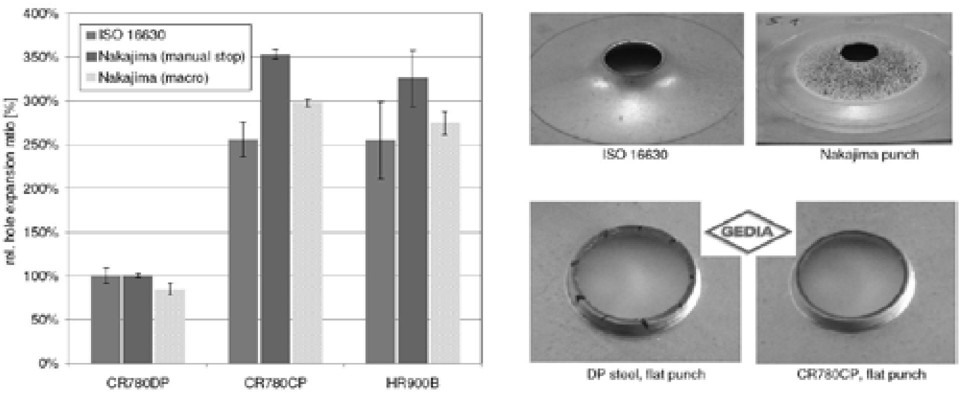

Fig. 3: Results from hole expanding test according to ISO 16630 and Najakima setup, both independently scaled to 100% for CR780DP (left). The photographs show the different sample geometries used in the diagram (top) and additional customer trials (bottom).

The bending test represents the material's resistance to cracks originating from the surface region and not from the cut edge as in HET. In difference to tensile testing, uniaxial tensile strain turns to a significant triaxial strain state already close to the surface. Thus, the bending test results in Fig. 4 represent an additional material property. Highest bending angle is tolerated by CR780CP, approximately 10 per cent less is HR900B. Significant lower bending values of 80° are observed for CR780DP. The same tendency of bending in Fig. 4 and HER in Fig. 3 may be explained by the advantageous effect of microstructural homogeneity on both tests [10,11], however different the tests are. The deviation with respect to the test direction may be explained by the banded structure in longitudinal direction owing the rolling process that is more pronounced for CR780DP than for the other steels.

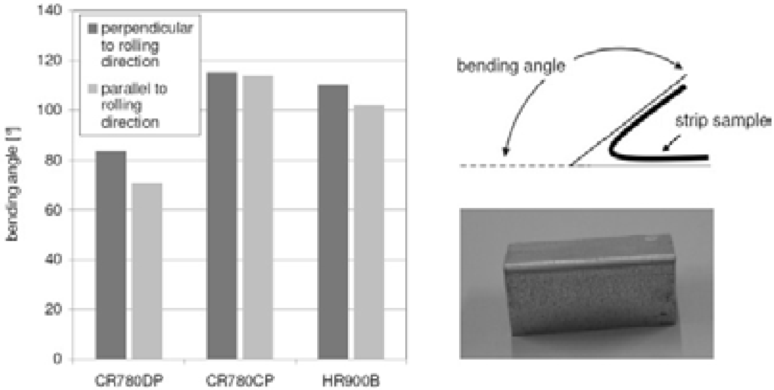

Fig. 4: Maximum bending angle according to VDA238-100, the orientation refers to the rolling direction in agreement with Fig. 2

Fig. 5 shows the part of the forming limit curve between plane strain (vertical axis) and biaxial stretching (bisecting line). The amount and position of minimum major strain is almost the same for all steels within the investigated region. In contrast to the total elongation obtained from tensile test, CR780CP and HR900B do not show poorer performance than CR780DP within the investigated region of strain.

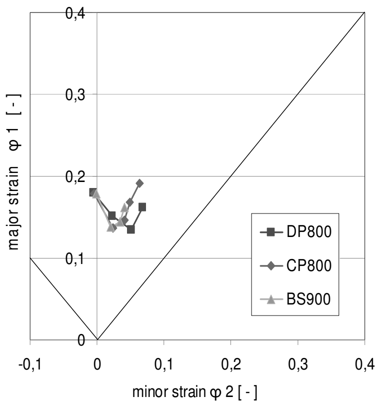

Fig. 5: Forming limit curve representing the range between plane strain to biaxial stretching

Another aspect of formability is given in Fig. 6. The diagram illustrates that under the given experimental condition the maximum drawing ratio of both CR780DP and CR780CP is 1.82 before cracking occurs at a drawing ratio of 2.0. The results are in accordance to further investigation that showed the same maximum drawing depth at increasing blank holder force and constant drawing ratio. HR900B tolerates a slightly higher drawing ratio of 2.0. The maximum drawing forces represent the material's strength levels.
To analyze the different materials performances in stamping trials the complex test form shown in Fig. 7 was chosen. The blank geometry was optimized in order to get intact components. It was successful in case of CR780CP und HR900B, cracking occurred at all settings at CR780DP, in most cases originating from the bottom edge of the component. The local strains were assessed; though no distinct

hints for failure could be defined. The amount of strain and thinning in any cases is between the values of CR780CP and HR900B.

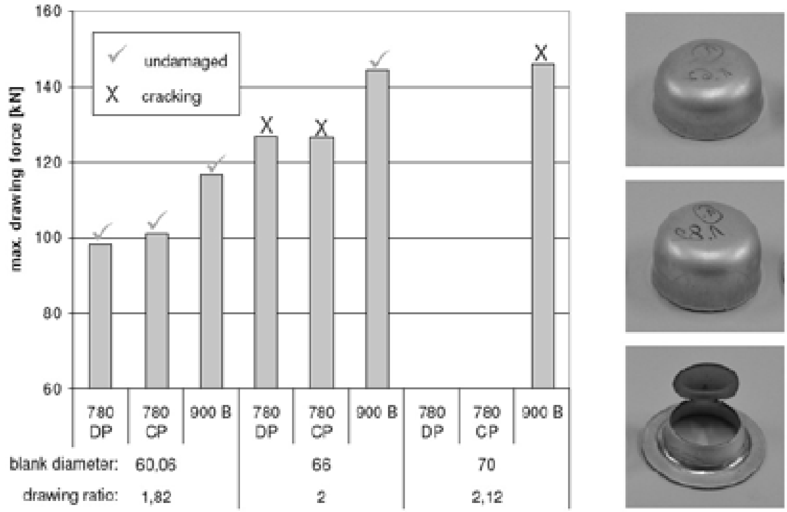

Fig. 6: Cup drawing results (left) and CR780CP as example of drawn cups with increasing drawing ratio (1,67, 1.82, 2.0) from top to bottom (right)

Certainly, the experimental procedure allows only a rough sight on the materials owing the variance of possible parameters. However, several subsequent strain operations that characterize the history at the point of failure, is obviously rather tolerated by the complex phase and bainitic than the dual phase structure. Yet it should be emphasized that the complexity of the test form is highly challenging regarding the strength level of the investigated material.

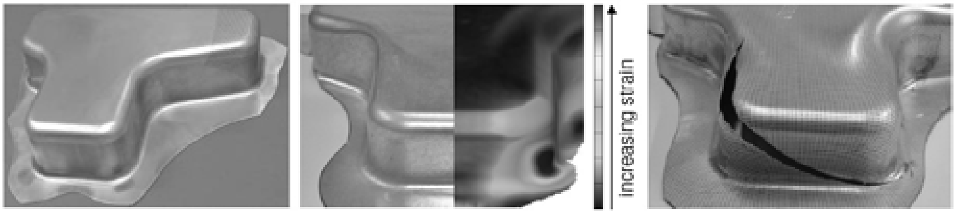

Fig. 7: CR780CP component (left) overlayed by Mises strain distribution as obtained from optical analysis (center) and cracked CR780DP component with grid pattern (right)

Conclusions

The comparison of three hot dip galvanized steels that possess similar tensile strength levels of 800 – 900 MPa but very different yield ratios result in individual collections of properties that cannot be concluded from a single tensile test or the steel denotation given in standard specifications. The materials ability for realizing a specific component is characterized by manifold different aspects, all of them originate from microstructure.

The main characteristics of the investigated hot dip galvanized steels are

- CR780DP consists of dual phase microstructure, CR780CP of complex phase microstructure with high amount of bainite and HR900B is fully bainitic.
- The cold rolled steels CR780DP and CR780CP satisfy the specifications of DIN EN 10346 and VDA 239.
- The investigated CR780CP and HR900B steels have 2.5 times higher hole expansion ratios than first generation CR780DP and 30% better bending performance
- CR780CP and HR900B show the same or even slightly better performance in cup drawing and stamping trials.

Particularly the stamping trials demonstrate the potential of multiphase steels regarding microstructural design. Thus, facing specific problems that may not be solved by substitution of a “first generation” DP steel by an advanced DP steel it is worth to consider the application of CP- and bainitic steels.

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