DOCOL®
THE AUTOMOTIVE STEEL

# Docol® press hardening steel

Technical brochure

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SSAB

For decades now, Docol Press Hardening Steel (PHS) has offered excellent properties for complex designs and it continues to do so today. Developed specifically for the automotive industry, Docol PHS steel offers a wide range of grades and dimensions. There are plenty of reasons to consider these materials.

Common for all of the grades are:

- Consistency in quality with stable chemical compositions.
- Excellent heat treatment properties.
- Tight tolerances and top performance in your workshop for every batch.
- Can be welded using most common techniques.

Helping you realize the full potential of your steel choice is one of our biggest goals. If you need any help or assistance with this, please contact our experts who can provide extensive welding support and recommendations.

Docol PHS steel is available as both cold and hot rolled in thicknesses ranging from 0.7–6 mm. Docol PHS is only available in uncoated condition.

## MECHANICAL PROPERTIES, TYPICAL VALUES

| Steelgrade | Product type | Thickness (mm) | Yield strength $R_e$ Typical (MPa) | Tensile strength $R_m$ Typical (MPa) | Elongation $A_{80}$ Typical (%) |
|---|---|---|---|---|---|
| Docol PHS CR 1500 | Rolled | 0.70–3.00 | 960 | 1060 | 4 |
| Docol PHS CR 1500 | Annealed | 0.70–3.00 | 340 | 480 | 28 |
| Docol PHS CR 1500 | Hot stamped | 0.70–3.00 | 1200 | 1590 | 6 |
| Docol PHS HR 1500 | Rolled | 2.00–6.00 | 570 | 715 | 20 |
| Docol PHS HR 1500 | Annealed | 2.00–6.00 | 350 | 530 | 25 |
| Docol PHS HR 1500 | Hot stamped | 2.00–6.00 | 1200 | 1590 | 6 |
| Docol PHS CR 1800 | Rolled | 0.70–3.00 | 970 | 1070 | 4 |
| Docol PHS CR 1800 | Annealed | 0.70–3.00 | 350 | 500 | 27 |
| Docol PHS CR 1800 | Hot stamped | 0.70–3.00 | 1300 | 1800 | 6 |
| Docol PHS CR 2000 | Rolled | 1.00–3.00 | 980 | 1100 | 4 |
| Docol PHS CR 2000 | Annealed | 1.00–3.00 | 330 | 530 | 26 |
| Docol PHS CR 2000 | Hot stamped | 1.00–3.00 | 1380 | 2040 | 5 |
| Docol PHS HR 2000 | Rolled | 2.00–6.00 | 490 | 690 | 18 |
| Docol PHS HR 2000 | Annealed | 2.00–6.00 | 330 | 540 | 27 |
| Docol PHS HR 2000 | Hot stamped | 2.00–6.00 | 1360 | 2040 | 6 |

Mechanical properties are valid in transverse direction.

## CHEMICAL COMPOSITION

| Steelgrade | C (%) | Si (%) | Mn (%) | P (max %) | S (max %) | Cr (max %) | B (%) | Nb+Ti (max %) |
|---|---|---|---|---|---|---|---|---|
| Docol PHS CR 1500 | 0.20–0.25 | 0.15–0.35 | 1.00–1.35 | 0.025 | 0.005 | 0.35 | 0.0020–0.0050 | |
| Docol PHS HR 1500 | 0.20–0.25 | 0.15–0.35 | 1.00–1.35 | 0.025 | 0.005 | 0.35 | 0.0020–0.0050 | |
| Docol PHS CR 1800 | 0.27–0.33 | 0.15–0.35 | 1.00–1.45 | 0.025 | 0.010 | 0.35 | 0.0008–0.0050 | |
| Docol PHS CR 2000 | 0.30–0.38 | 0.15–0.35 | 1.10–1.50 | 0.025 | 0.005 | 0.35 | 0.0010–0.0050 | 0.2 |
| Docol PHS HR 2000 | 0.30–0.38 | 0.15–0.35 | 1.10–1.50 | 0.025 | 0.005 | 0.35 | 0.0010–0.0050 | 0.2 |

## TOLERANCES

Cold-rolled (UC): Tolerances in accordance to EN10131.
Hot-rolled (UC): Tolerances in accordance to EN10051.
Customized dimensional and shape tolerances are available on request.

## COATINGS AND SURFACE TREATMENTS

All surface treatments are in accordance with RoHS directive (2011/65/EU) and do not contain Chromium VI (Cr6+). Surface treatments provide only temporary surface protection during transportation and storage. In order to avoid corrosion damages, care must be taken to keep the products dry during transportation and storage. If they become wet, they must be separated and situated so that they are dried quickly.

| Surface Coating | Available surface treatment |
|---|---|
| UC (Cold-rolled) | Oiled |
| UC (Cold-rolled) | Unprotected |

## FABRICATION AND OTHER RECOMMENDATIONS

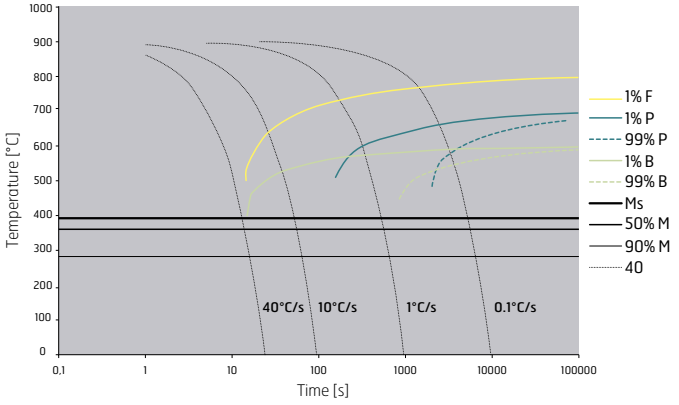
For information concerning fabrication, see SSAB's brochures on www.ssab.com or consult Tech Support at techsupport@ssab.com. Appropriate health and safety precautions must be taken when bending, welding, cutting, grinding or otherwise working on the product.

## HEAT TREATMENT AND CRITICAL COOLING RATE

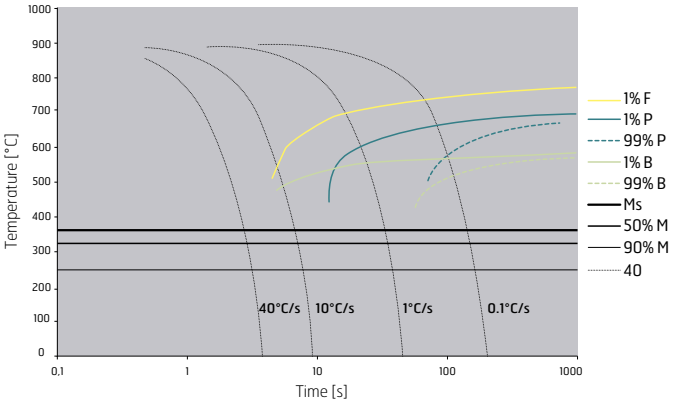
Austenitization and cooling parameters are critical in order to obtain a fully martensitic microstructure. Typical austenitization temperature and time is 870–950°C for 3–5 minutes. With decreasing furnace temperature, the austenitization time increases. The heating cycle is also very much depending on capacity of the equipment/furnace used and the sheet thickness. Figure below shows theoretical CCT diagram. The critical cooling rate obtained to achieve a martensitic microstructure is >30°C/s for PHS 1500 and PHS 1800 and > 50°C/s for PHS 2000. Theoretical CCT diagrams are based on the material temperature, not the furnace temperature.

## COOLING RATE

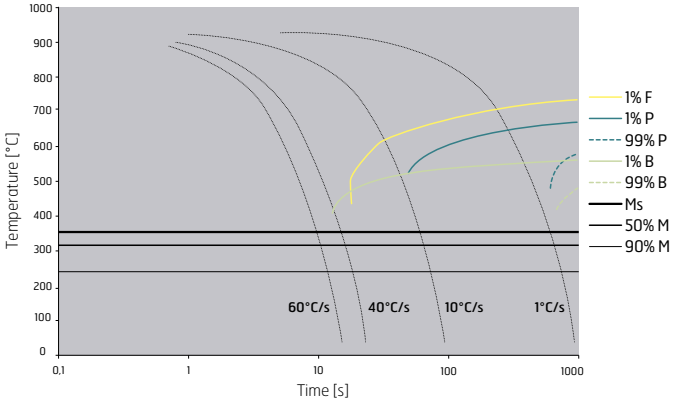
**Docol PHS 1500**




**Docol PHS 1800**




**Docol PHS 2000**



## BENDABILITY

Table below show typical bending angle and mechanical properties in longitudinal and transversal testing directions. Properties are evaluated in hot stamped condition and bending test is according to standard VDA 238-100.

| Test direction | Property | Docol PHS CR 1500 | Docol PHS CR 1800 | Docol PHS HR 2000 | Docol PHS CR 2000 |
|---|---|---|---|---|---|
| RD | Angle [°] | 67 | 48 | 51 | 43 |
| | Rp02 [MPa] | 1198 | 1358 | 1340 | 1383 |
| | Rm [MPa] | 1590 | 1906 | 2030 | 2031 |
| | A50 [%] | 7.4 | 6.6 | 8.0 | 6.1 |
| TD | Angle [°] | 88 | 62 | 41 | 51 |
| | Rp02 [MPa] | 1203 | 1358 | 1357 | 1395 |
| | Rm [MPa] | 1590 | 1911 | 2044 | 2038 |
| | A50 [%] | 6.5 | 5.9 | 8.6 | 5.1 |

Properties are evaluated in hot stamped condition
B = Batch annealed before hot stamping
BO = Full hard condition before hot stamped

Example of bending angle thickness dependence. Bending test according to standard VDA 238-100.

| Steelgrade | Condition | Thickness (mm) | Bending angel RD (*) | Bending angel TD (*) |
|---|---|---|---|---|
| Docol PHS CR 2000 | Hot stamped | 1.11 | 53 | 56 |
| Docol PHS CR 2000 | Hot stamped | 1.65 | 38 | 52 |
| Docol PHS CR 2000 | Hot stamped & Baked | 1.11 | 65 | 79 |
| Docol PHS CR 2000 | Hot stamped & Baked | 1.65 | 53 | 71 |

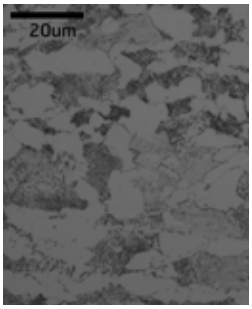
## MICRO STRUCTURE

PAG size in hot stamped condition.

Below measurement of the former austenite grain size was performed using the circular intercept method according to ASTM E112 (Hilliard Single-Circle Procedure), with the reservation that only one field of vision was measured.

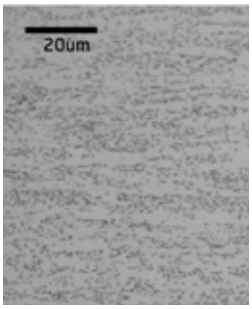
The radius of the used circle set to 64 µm. EBSD map length, 200 µm.

| Sample | ECD [µm] | Radius [µm] |
|---|---|---|
| Docol PHS CR 2000 (RD) | 7.3 | 64 |
| Docol PHS CR 2000 (TD) | 6.4 | 64 |

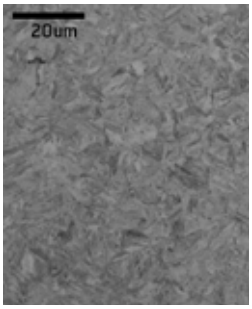



As-recieved hot rolled condition, ferrite and perlite.


As-recieved cold rolled condition, ferrite and perlite.




Annealed condition cold rolled, ferritc matrix with spheroidized perlite.




Microstructure after hot stamping cold rolled condition, martensite.

## WELDING

In the **Table 1**, some examples from resistance spot welding of press hardened Docol boron steels are shown. The welding results presented in the table have been obtained by means of stationary MFDC machine. Docol boron steels can also be welded with single-phase AC machines. The available current ranges can differ somewhat, but the difference is not large. The obtained values show that the steels have large welding current ranges despite their high strength in hardened condition.

**Table 1** Examples of measured welding current range for resistance spot welding of Docol PHS CR1500, Docol PHS CR1800 and Docol PHS CR2000.

| Steel grade | State of the steel before welding | t (mm) | Welding current range[2] △I (kA) | Min–Max current[3] (kA) | Type of failure | Type of testing |
|---|---|---|---|---|---|---|
| Docol PHS CR1500 | Hot stamped[1] | 1,5 | 2,2 | 5,81–8,01 | Partial plug | Chisel test |
| Docol PHS CR1800 | Hot stamped[1] | 1,6 | 2,0 | 6,11–8,11 | Partial plug | Chisel test |
| Docol PHS CR2000 | Hot stamped[1] | 1,5 | 1,70 | 5,81–7,51 | Partial plug | Cross Tension test |

1) Sand blasted surface after hot stamping.
2) Welding the steels to itself by MFDC machine. The welding parameters according to SEP1220-2.
3) Min weld diameter $4\sqrt{t}$ according to SEP1220-2.

For uncoated press hardened steels, it is very important to ensure that no oxide residue remain on the surface after hardening. The reason is that spot welding of a steel with the oxide remaining in certain places on the surface does not give reliable and repeatable results. The scatter in the button diameters measured is normally very wide due to the variations in the contact resistance during welding. Therefore, remaining oxide residue on the surface of the uncoated press hardened steel should effectively be removed by sandblasting.

The spot welding of Docol boron steels to a steel with much lower strength, full plug failure will be obtained, but when welding to itself, the fracture will generally be partial plug failure. Interfacial failure mode appears usually on the spot welds where their nugget diameter is close to minimum required weld diameter. The reason for these failures is due to the increased alloying content necessary to able to reach the aimed hardenability in the steel during hardening operations.

### Strength of the spot-welds

The strength of the spot weld is very important for the performance of the spot welded component and be a function of sheet thickness, weld size and strength of the steel. The strength of the spot weld increases with increasing sheet thickness and increasing weld size, but there is no such straightforward relation between the strength of the steel and the strength of the spot welds.

The reason for the drop in cross tension strength for the steels with very high strength is due to higher alloying concept in the steel. Consequently, the hardness of the spot weld (hardness in the nugget zone and also in HAZ close to the nugget) is higher for higher grades of steels in comparison with DP steels or the other softer reference steels. These results demonstrate that the greatest benefit of spot welding Docol boron steels is obtained in shear loading. Peel loading and cross tension loading of spot welds, if possible, should be avoided for Docol boron steels. As a reference, typical strength and hardness values for the specific nugget diameter of spot welds are tabulated in **Table 2** for three different of Docol borons steels.

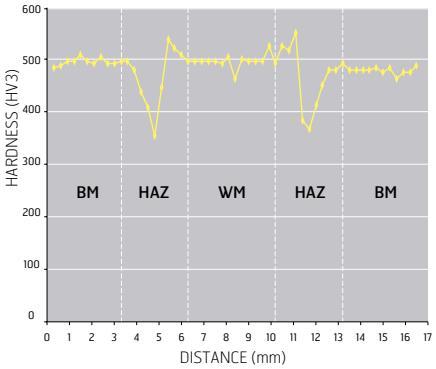
**Table 2** Typical load carrying capacity of minimum weld nugget diameter of Docol PHS CR1500, Docol PHS CR1800 and Docol PHS CR2000 in both of shear and cross-tensile modes. Typical hardness values (HV1) across the weld are also tabulated for three of the steels.

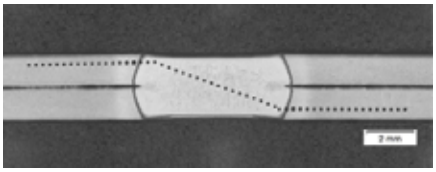
| Steel grade | State of the steel before welding | t (mm) | Shear tensile strength for $d_{min}$ [2] (kN) | Cross tensile strength for $d_{min}$ [2] (kN) | Typical hardness across the weld (HV1) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | BM | HAZ min | HAZ max | WM |
| Docol PHS CR1500 | Hot stamped[1] | 1,5 | 18,0 | 5,6 | 496[3] | 356[3] | 553[3] | 497[3] |
| Docol PHS CR1800 | Hot stamped[1] | 1,6 | 17,7 | 4,3 | 577[4] | 342[4] | 585[4] | 543[4] |
| Docol PHS CR2000 | Hot stamped[1] | 1,5 | 16,1 | 3,8 | 630[4] | 368[4] | 652[4] | 622[4] |

1) Sand blasted surface after hot stamping
2) $d_{min} = 4\sqrt{t}$ according to SEP1220-2
BM= Base metal
HAZ= Heat Affected Zone,
3) Hardness measurement with HV3
4) Hardness measurement with HV1
WM= Weld Metal

## TYPICAL HARDNESS CURVES FOR RSW WELDED DOCOL PHS STEEL

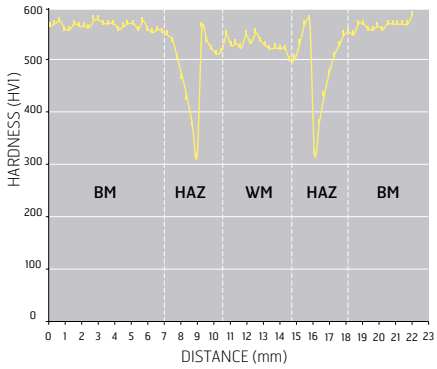
HARDNESS ACROSS THE WELD DOCOL PHS CR1500
T=1,5 mm Imin = 5,81kA



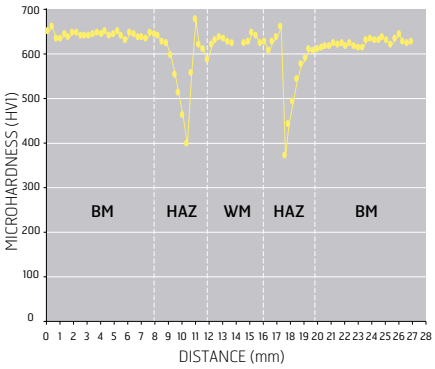
Cross section and hardness curve across spot weld of Docol PHS CR1500 (sheet thickness 1.5 mm), The steel is resistance spot welded to itself. Welding parameters are selected according to SEP1220-2.

HARDNESS ACROSS THE WELD DOCOL PHS CR1800
T=1,6 mm Imin = 6,11kA




Cross section and hardness curve across spot weld of Docol PHS CR1800 (sheet thickness 1.6 mm). The steel is resistance spot welded to itself. Welding parameters are selected according to SEP1220-2.

HARDNESS ACROSS THE WELD DOCOL PHS CR2000
T=1,50 mm Imin = 5,81 kA




Cross section and hardness curve across spot weld of Docol PHS CR2000 (sheet thickness 1.5 mm). The steel is resistance spot welded to itself. Welding parameters are selected according to SEP1220-2.

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