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Weldability and Process Reliability
Influence of Welding Parameters

by

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Resistance Spot Welding of Uncoated and Zinc Coated Advanced High-Strength Steels (AHSS) Weldability and Process Reliability Influence of Welding Parameters

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Abstract

In lightweight body shell mass production of automobiles the resistance welding process for joining high-strengths multi-phase steels, also called advanced high-strength steels (AHSS), is the most important joining procedure. For uncoated and hot dip zinc coated high-strength TRIP steels and complex phase steels, statements, about process reliability in resistance spot welding based on three-dimensional weldability lobes will be given. A comparison of weldability lobes of uncoated and hot dip zinc coated high-strength steel sheets with reference sheets of mild steels will be carried out. This is realized with different electrode forces for short-, medium- and long-time welds. Especially the influence of the electrode force and of the welding time has been studied in three-dimensional weldability lobes. A procedure for welding parameter optimization in regard to maximal process reliability for AHSS is applied. Based on the electrode wear and the process reliability, statements relating to the weldability of AHSS are formulated. Furthermore, results concerning the influence of the welding parameters on the hardness and the fatigue behavior of the spot welded joints will be given.

1 Introduction

Resistance spot welding is the dominant joining technique for thin sheet metal. This applies in particular to high-strength steels (HSS) and ultra high-strength steels (UHSS) joining in lightweight body shell mass productions of automobile. The application of UHSS materials in conjunction with economically efficient and reliable joining processes helps saving costs and conserving resources (weight reduction, energy minimization) and provides at the same time consistent or improved safety of the passenger cell (crash optimization). In this context, the UltraLight Steel Auto Body design (ULSAB) and New Steel Body (NSB®) are referred to [1-2]. In recent years, further joining techniques such as self-piercing riveting, clinch joining and laser welding have increasingly been applied in specific fabrication steps in addition to spot welding. But in the case of high-strength multi-phase steels, also called advanced high-strength steels (AHSS), this joining techniques are not as efficient as resistance spot welding. For more information on AHSS see [3]. In this *paper,* statements about process reliability and weldability for uncoated and hot dip zinc coated high-strength TRIP steels and complex phase steels will be given based on three-dimensional weldability lobes and electrode wear results for these special AHSS. A comparison of the results of the special AHSS sheets with reference sheets of mild steels will be carried out, too. With different electrode forces for short-, medium- and long-time welding especially, the influence of the electrode force and of the welding time is studied in three-dimensional weldability lobes.

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The influence of electrode cap type on the welding current ranges has been studied too [4]. Especially, the results for uncoated and hot deep zinc coated TRIP steels will be given in [4].

Furthermore, some statements on the strength, the hardness and the fatigue behavior for the spot welded joints of the AHSS will be given. Summarizing one can say that the process reliability and the weldability for spot welded AHSS will be guaranteed, and it can be stated that strength and the fatigue behavior of the spot welded AHSS will be better than in the case of mild steel sheets.

2 Quality limits, welding ranges and weldability lobes in resistance spot welding

To ensure process reliability during resistance spot welding under conditions of the practice, of the knowledge of welding range or welding current range (WCR) is of basic importance. Different WCR are obtained depending on the selected welding parameters. The primary welding parameters of resistance spot welding are the r.m.s.-value of welding current I, the stationary electrode force F_e and the welding time t_w.

In resistance spot welding, the WCR is usually defined on the basis of requirements imposed on the root mean square value (r.m.s.-value) of welding current during spot welding. A particular requirement is that the r.m.s.-value of welding current must be kept within certain limits set by quality demands placed on the spot weld diameter.

The lower limit of the r.m.s.-value of welding current results from the requirement of a minimum spot weld diameter, whereas the upper limit of the welding current is given by the physics of the welding process. The lower quality limit can in principle be optionally set by making a requirement on the spot weld diameter depending on the quality and strength demands, respectively, placed on the spot weld. Commonly used lower quality limits are spot weld diameters of $3.5\sqrt{t}$ or $4\sqrt{t}$, whereby t is the sheet thickness.

These lower quality limits are then also referred to as $3.5\sqrt{t}$ or $4\sqrt{t}$ -limit. The situation is completely different with the upper quality limits. The maximum admissible upper quality limit is set by the physics of the spot welding process. It is usually referred to as splash limit I_{SL}. This limit constitutes a stability limit of the resistance spot welding process. The splash limit is the very quality limit at which a spot weld can still be performed without the occurrence of a splash. In order to ensure that at and below this limit no splashes do in fact occur, it is necessary in setting this limit to take into account that it varies within a certain scatter band. The variation of the upper quality limit depends on the welding parameters of electrode force and welding time, on the material to be joined and its coating, on the electrode cap types, the applied current form as well as on the electrical and mechanical machine properties of the spot welding unit.

In metrological determination of the spot weld diameter, and hence of the upper and lower quality limits, it must be considered that the measuring results are dependent on the test method and on the fracture type. Consequently, different values of spot weld diameters are, for instance, obtained if a peel test is conducted in the place of a torsion test. This applies even more to AHSS. For this reason, test procedure and fracture type must always be indicated in welding range determinations.

With d_{uT} being the spot weld diameter determined in the torsion test which sets the lower quality limit, and d_{oT} being the spot weld diameter determined in the torsion test which represents the upper quality limit, the spot weld diameter difference

$$\Delta d = d_{oT} - d_{uT} \qquad 2.1$$

is a measure of the achievable quality range during resistance spot welding. Using the corresponding r.m.s.-values of welding current I_u for the lower quality limit ($d = d_{uT}$) and I_o for the upper quality limit ($d = d_{oT}$), the welding current range assigned to (2.1)

$$\Delta I = I_o - I_u \tag{2.2}$$

is then obtained for the r.m.s.-value of welding current. Hence, the WCR, by definition, is the setting range of the welding current. Particularly in the definition of the welding range, a welding current difference according to

$$\Delta I = I_{SL} - I_{x\sqrt{t}} \tag{2.3}$$

is usually assumed, whereby the lower and the upper quality limits are set by the $x\sqrt{t}$ -limit and by the splash limit, and x being optional depending on the minimum quality requirements of the spot weld. A frequent selection is x = 3.5 or even x = 4.0, as already mentioned above.

This allows it to formulate the following definition of the three-dimensional welding range.

The representation of the difference ΔI of the r.m.s.-value of welding current, according to Equation (2.3), between the upper and the lower quality limit of the quality feature spot weld diameter as a function of the (stationary) electrode force F_e and of the welding time t_w

$$\Delta I = f\,(F_e, t_w) \tag{2.4}$$

is referred to as three-dimensional I-F-t_w weldability lobe. From the three-dimensional weldability lobes according to this definition, the classic two-dimensional weldability lobes can be derived as special representations [5 - 10].

For a constant electrode force F_e = const., the two-dimensional t_w-I-weldability lobe is given by

$$t_w = t_w\,(I, F_e = \text{const.}), \tag{2.5}$$

and for constant welding time t_w = const., the two-dimensional F_e-I-weldability lobe is given by

$$F_e = F_e\,(I, t_w = \text{const.}). \tag{2.6}$$

In this paper, only the three-dimensional form of (2.4) is used to describe the welding ranges. Examples of two-dimensional weldability lobes for AHSS are given in [10 - 12].

3 Process reliability of the spot welding process

In order to show the spot welding process reliability of different AHSS grades, the corresponding weldability lobes were first set up. These investigations were carried out by a welding gun with electrode caps of type F16, flattened to face diameter of 5.5 mm. Characteristic data of the tested materials are summarized in *Table 1*.

Grade definition by TKS	Grade definition by future Standardization	Sheet Thickness [mm]	Zinc coating weight [g/m²]	Yield strength [MPa]	Tensile strength [MPa]	Facture strain [-]
DC 01	DC 01	1.50	-	185	318	42
DX 54D+Z	DX 54D+Z	1.50	100	157	300	46
RA-K 40/70	HT 700T	1.60	-	452	738	28
RA-K 40/70+Z	HT 700T+Z	1.60	100	473	710	32
CP-W 800	HT 800C	1.65	-	791	896	13
CP-W 800+Z	HT 800C+Z	1.50	190	688	913	11
MS-W 1200	-	1.60	-	1146	1381	8

Table 1: Characteristic values of the materials

The welding times were varied in the steps of 6, 10 and 20 cyc. as short-, medium- and long-time welding for each of the sheet material. The electrode forces were varied in the case of high-strength steels in the steps of 3.5, 4.5 and 5.5 kN. And in the case of low-strength steels, the electrode forces were varied in the steps of 2.2, 2.6 and 3.0 kN. The common quality feature is the spot weld diameter from the torsion test.

The process reliability of the spot welding process depends on the size of the WCR. Roughly speaking, the process reliability will be higher if the size of WCR becomes bigger for the chosen welding parameters. The WCR is determined by the welding parameters electrode force F_e and welding time t_w and influenced by a lot of influencing factors [7]. Thus, the process reliability depends on the selection of welding parameters and on these additional influencing factors. Important influencing factors are the shape and material of the electrode caps, the base metal and the coating of the steel sheets as well as the static and dynamic mechanical machine properties of the welding equipment [7].

For the case of spot welding uncoated and zinc coated mild steel sheets, it is well known that the size of WCR becomes bigger for uncoated material. For the reference materials of low strength, the mild steel sheets DC01 (uncoated) and DX54D+Z (hot dip zinc coated), *Figures 1 - 2* show these connections. But, as can be seen, the impact of coating is not significant in all cases of chosen welding parameters.

The WCR belonging to the different welding parameter combinations are given in *Tables 2 - 3*.

Material	F_e [kN]	6 cyc.		10 cyc.		20 cyc.	
		$I_{4\sqrt{t}}$	I_{SL}	$I_{4\sqrt{t}}$	I_{SL}	$I_{4\sqrt{t}}$	I_{SL}
DC 01	2.2	7.35	7.75	5.85	6.45	4.60	6.70
	2.6	7.55	8.55	6.00	7.30	4.90	7.60
	3.0	7.70	8.90	6.15	8.00	5.15	8.40
RA-K 40/70	3.5	5.40	6.25	4.70	6.15	4.20	5.80
	4.5	5.70	7.00	5.00	6.75	4.40	6.55
	5.5	6.00	7.00	5.10	6.95	4.90	7.55
CP-W 800	3.5	6.30	7.65	5.45	7.30	4.20	7.15
	4.5	6.55	8.60	5.80	7.50	4.60	7.55
	5.5	6.90	9.00	6.10	7.80	4.80	8.10

Table 2: Limits of welding current for uncoated sheets

Material		DC 01			RA-K 40/70			CP-W 800		
electrode force [kN]		2.2	2.6	3.0	3.5	4.5	5.5	3.5	4.5	5.5
welding current range		ΔI [kA]			ΔI [kA]			ΔI [kA]		
weldig time in cyc.	6	0.40	1.00	1.20	0.85	1.30	1.00	1.35	2.05	2.10
	10	0.60	1.30	1.85	1.45	1.75	1.85	1.85	1.70	1.70
	20	2.10	2.70	3.25	1.60	2.15	2.65	2.95	2.95	3.30

Table 3: Welding ranges for uncoated sheets

By three-dimensional weldability lobes it is possible to study the influences of the welding time and electrode force in a common diagram at the same time. The influences of increasing electrode force and of a prolongation of welding time on the WCR are different, due to the materials, *Figures 1 - 4*.

With increasing electrode force, the upper and lower quality limits are shifted towards higher current for all tested steel sheets. The size of WCR depends on the materials and will be different with increased electrode force. In the case of the TRIP steel RA-40/70, there is a significant increase of the WCR with rising electrode force, *Figure 3*. On the other hand, the influence of the electrode force for the complex phase steel CP-W800 is less significant, *Figure 4*. A welding time prolongation is more significant than an electrode force increase. Especially for long-time welding (20 cyc.) and for higher electrode forces (5.5 kN) there are significant bigger WCR. From the WCR of the weldability lobes one can deduce statements with respect to the process reliability which can reached with the given spot welding equipment, when welding the tested AHSS. Especially in the case of long-time welding (20 cyc.) and of high electrode forces (5.5 kN), the highest process reliability occurs, *Figures 1 - 4*. The three-dimensional F_e-t_w-weldability lobes for hot dip zinc coated AHSS are shown in *Figures 5 - 6*.

The corresponding welding parameter combinations (F_e, t_w) and welding ranges are given in *Tables 4 - 5.*

Due to the zinc influence on the electrical process parameters and on the quality feature weld diameter, we have a different situation than in the case of uncoated AHSS. Thus, the size of WCR corresponding to given welding parameter combinations will be different from those in the uncoated case. For the hot dip zinc coated TRIP steel RA-K40/70+Z and the hot dip zinc coated complex phase steel CP-W800+Z, short-time welding is not sufficient in terms of the process reliability, since the WCR becomes too small, *Figures 5 - 6*. But this is from the view point of practice not a problem because short-time welding is not applied. For the TRIP steel RA-K 40/70+Z in the case of medium-time welding (10 cyc.) at a medium electrode force (4.5 kN) the size of WCR increases up to 0.9 kA. The size of WCR for long-time welding (20 cyc.) at medium forces (3.5 to 4.5 kN) lies between 0.9 and 1.3 kA for the steels RA-K40/70+Z and CP-W800+Z. Thus in this case we have sufficient high WCR to guarantee process reliability.

This means that sufficiently high ranges of WCR from 1.6 kA resp. 1.8 kA are available for the tested high-strength hot dip zinc coated multi-phase steels in the case of long-time welding (20 cyc.) with high electrode force (5.5 kN), *Figures 5 - 6*.

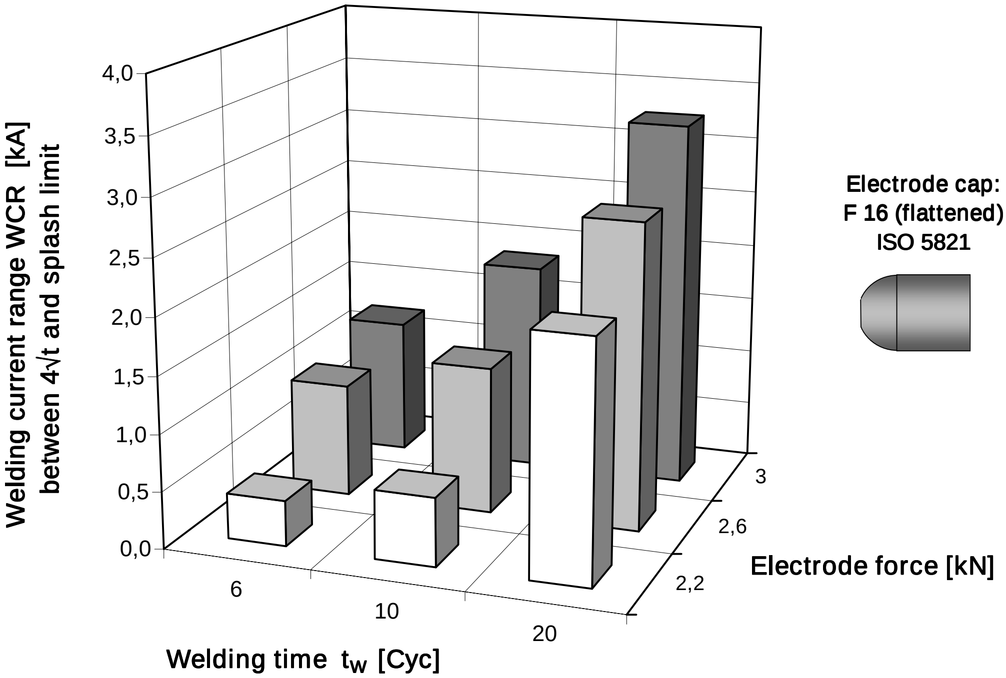


Fig. 1: Influence of the welding parameter on the weldability lobe
Steel grade: DC 01, thickness: 1.5 mm

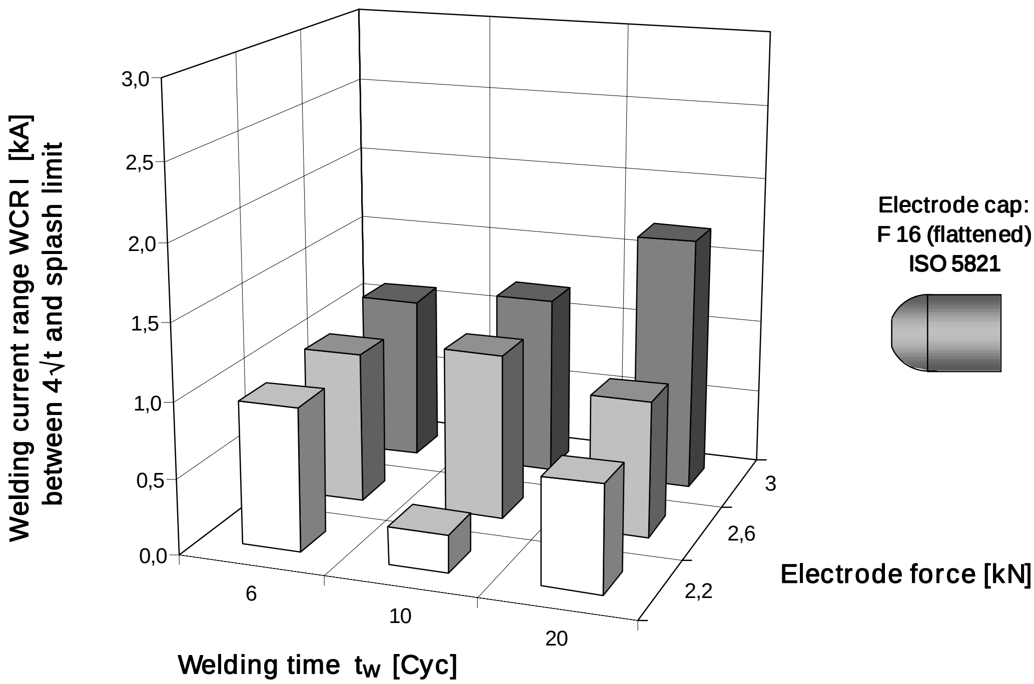


Fig. 2: Influence of the welding parameter on the weldability lobe
Steel grade: DX54D+Z, thickness: 1.65 mm

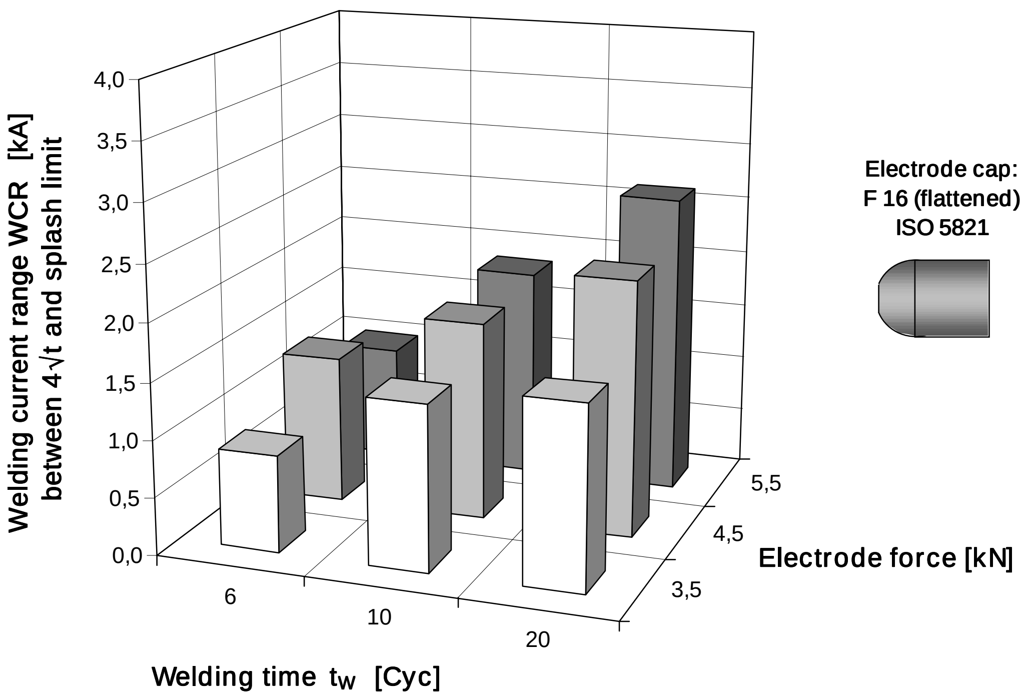


Fig. 3: Influence of the welding parameter on the weldability lobe
Steel grade: RA-K40/70 (TRIP 700), thickness: 1.6 mm

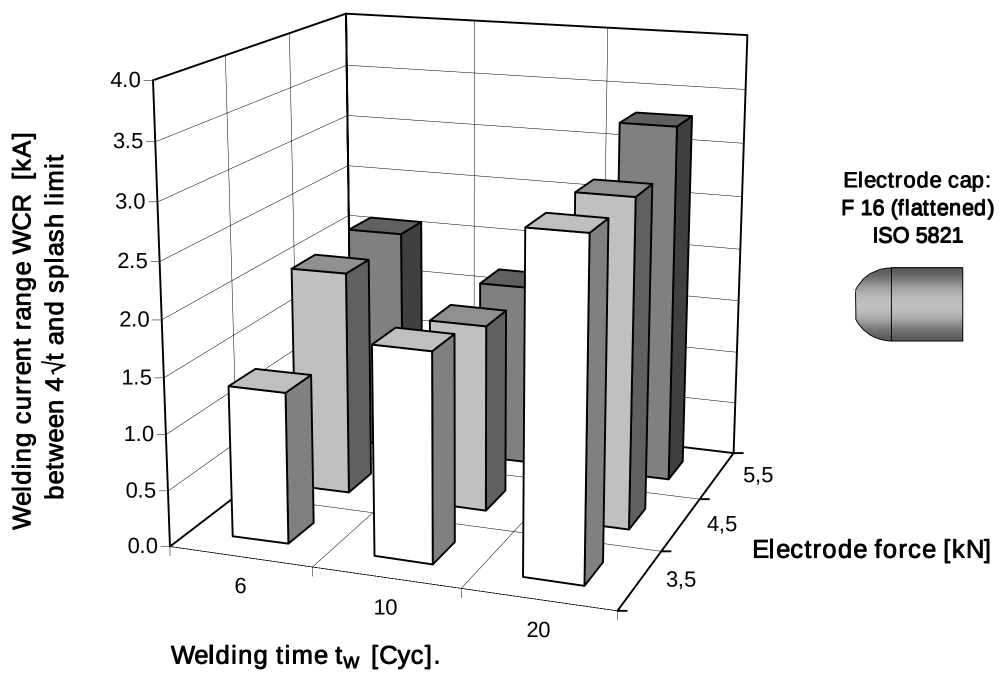


Fig. 4: Influence of the welding parameter on the weldability lobe
Steel grade: CP-W 800, thickness: 1.65 mm

Material	F_e [kN]	6 Cyc.		10 Cyc.		20 Cyc.	
		$I_{4\sqrt{t}}$	I_{SL}	$I_{4\sqrt{t}}$	I_{SL}	$I_{4\sqrt{t}}$	I_{SL}
DX 54D+Z	2.2	9.95	10.90	8.50	8.75	6.40	7.10
	2.6	10.05	11.05	8.65	9.75	6.75	7.65
	3.0	10.20	11.30	8.85	10.05	6.80	8.50
RA-K 40/70+Z	3.5	8.20	8.20	6.10	6.80	5.10	6.10
	4.5	8.75	9.15	6.50	7.35	5.40	6.25
	5.5	9.25	9.45	6.65	7.20	5.50	7.30
CP-W 800+Z	3.5	9.60	9.60	6.95	7.25	6.00	7.00
	4.5	10.15	10.15	7.10	7.90	6.15	7.45
	5.5	10.10	10.40	7.35	8.20	6.10	7.70

Table 4: Limits of welding current for hot dip zinc coated sheets

Material		DX 54D+Z			RA-K 40/70+Z			CP-W 800+Z		
electrode force in kN		2.2	2.6	3.0	3.5	4.5	5.5	3.5	4.5	5.5
welding current range		ΔI in kA			ΔI in kA			ΔI in kA		
welding time [Cyc.]	6	0.95	1.00	1.10	0.00	0.40	0.20	0.00	0.00	0.30
	10	0.25	1.10	1.20	0.70	0.85	0.55	0.30	0.80	0.85
	20	0.70	0.90	1.70	1.00	0.85	1.80	1.00	1.30	1.60

Table 5: Welding ranges for hot dip zinc coated sheets

Thus, for both the hot dip zinc coated TRIP steel RA-K40/70+Z and the complex phase steel CP-W800+Z there exists a sufficiently high process reliability. The highest process reliability occurs in all cases at the highest electrode forces. In the case of long-time welding for low, medium and high electrode forces, the highest process reliability occurs, *Figures 5- 6*.

4 Weldability of high-strength multi-phase steel sheets

As shown in Chapter 3, depending on the selection of the welding parameters electrode force F_e and welding time t_w, different process reliabilities can be realized. Based on different welding parameter combinations, different WCR occur. With optimal choice of welding parameter combinations, especially in the case of medium- and long-time welding, sufficiently high process reliabilities can be generated. But the existence of process reliability is not a sufficient condition for the weldability of the steel sheets. According to ISO 18278, both the possibility of spot welding and the reproducibility must be given at the same time.

The possibility of spot welding is guaranteed by the existence of determined welding parameter combinations for which a sufficiently high process reliability will be realized. The possibility of reproducibility for spot welding of a given material is only guaranteed by sufficiently little electrode wear. This is to say that the electrode life must be sufficiently long. It has been shown, see *Figures 7 - 8*, that for hot dip zinc coated high-strength steel sheet of RA-K40/70+Z and CP-W800+Z, the electrode life is sufficiently low. Therefore, it can be concluded that the weldability is guaranteed for both the multi-phase steels RA-K40/70+Z and CP-W800+Z. Due to larger WCR and longer electrode lives, a superior spot weldability for uncoated AHSS can be stated.

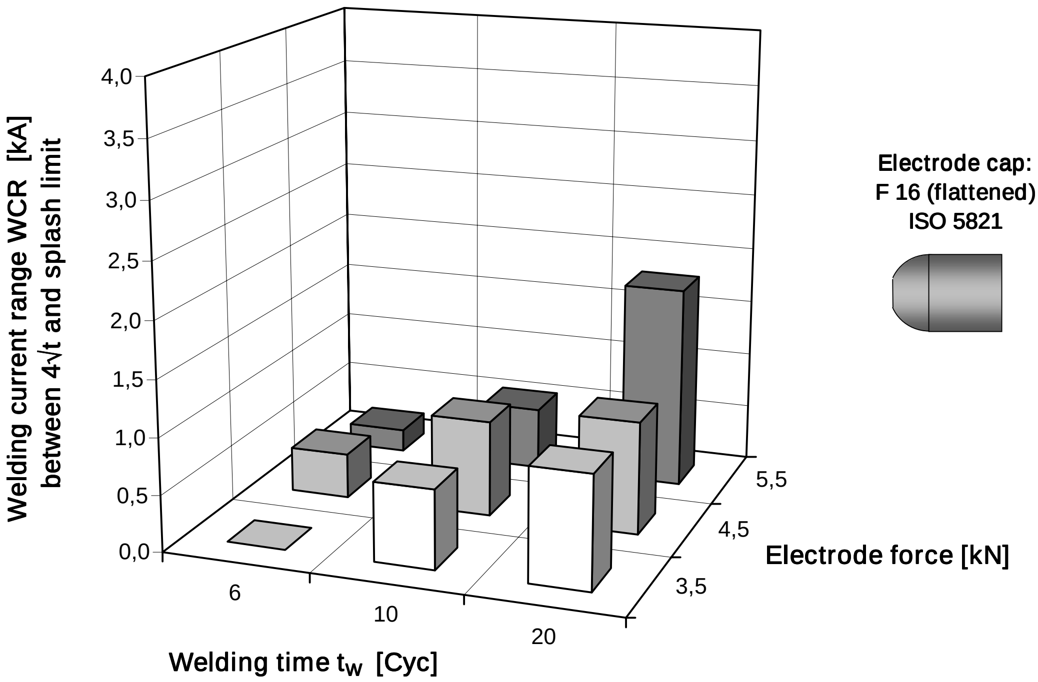


Fig. 5: Influence of the welding parameter on the weldability lobe
Steel grade: RA-K40/40+Z (TRIP 700), thickness: 1.5 mm

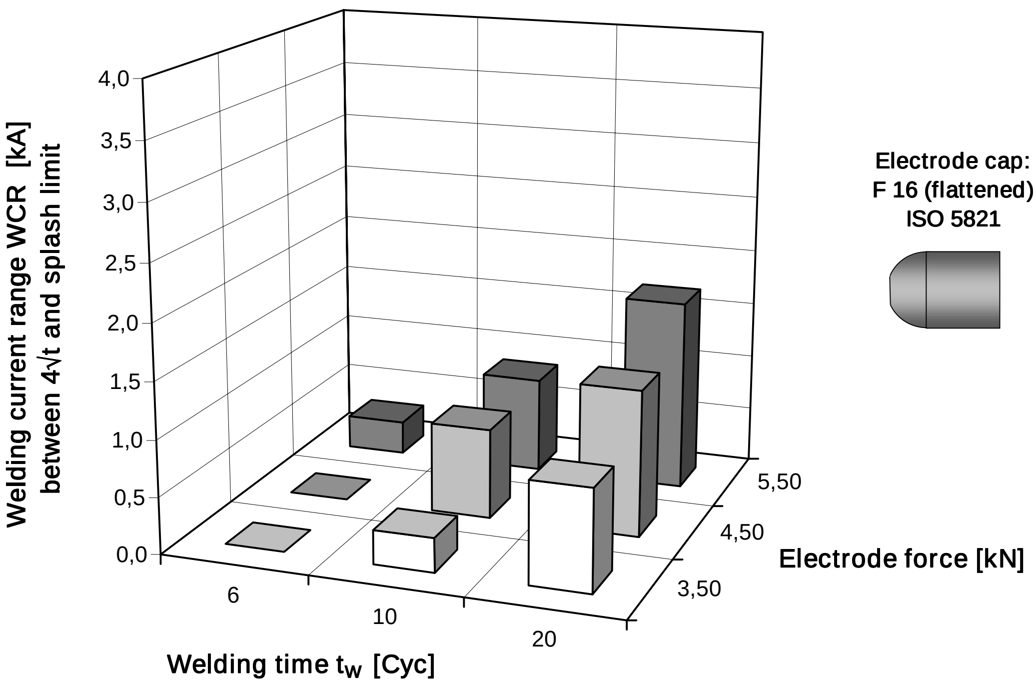


Fig. 6: Influence of the welding parameter on the weldability lobe
Steel grade: CP-W800+Z, thickness: 1.5 mm

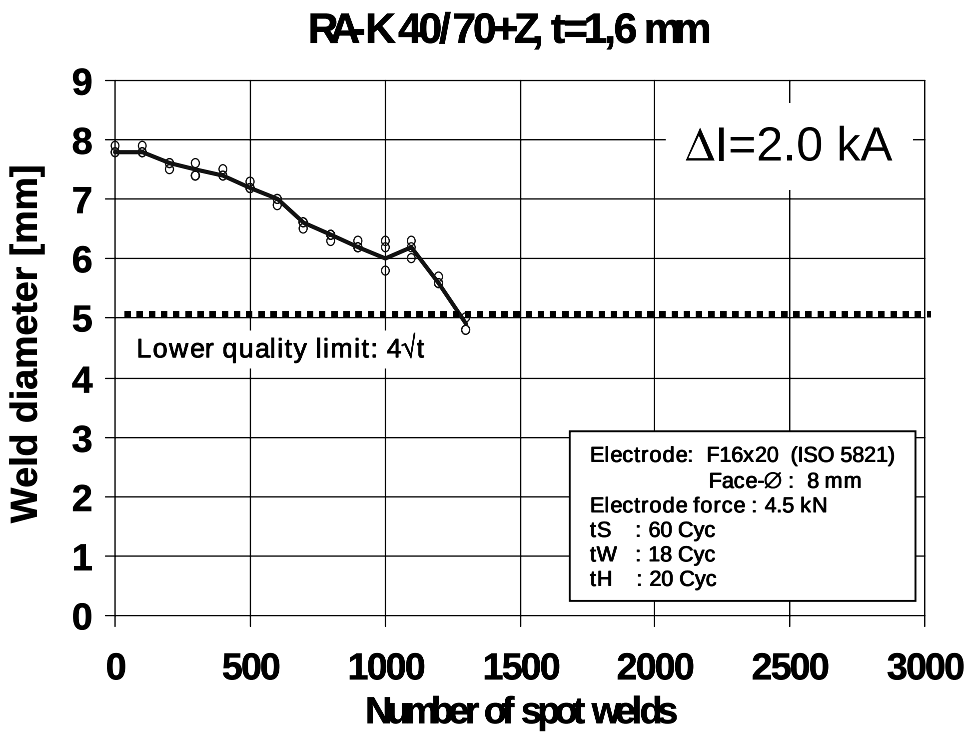


Fig. 7: Electrode life with the steel grade RA-K40/70+Z (TRIP 700), thickness: 1.6 mm

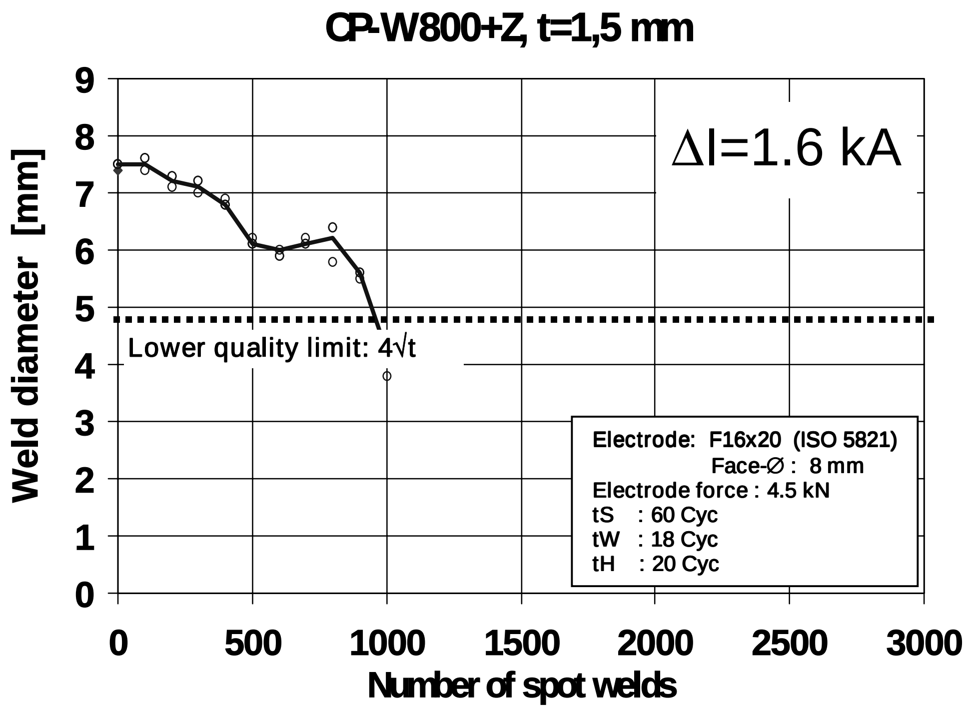


Fig. 8: Electrode life with the steel grade CP-W800+Z, thickness: 1.5 mm

5 Hardness, strength and fracture behaviour of spot welded joints

Typical weld nugget hardness characteristics for the tested AHSS are given in *Figure 9*. For the tested uncoated AHSS and the mild reference steel grade, two welding parameter combinations were chosen. Especially for the electrode forces of 5.5 kN and 3.9 kN (mild steel), respectively, medium- and a long-time welding (10 cyc. and 20 cyc.) were carried out. As a result, it can be seen that the influence of a prolongation of the welding time is negligible. Depending on the choice of the measuring point, a higher or a lower value determines the hardness. Normalized weld nugget hardness characteristics due to the formula

$$hv_{0.5} = \frac{HV_{0.5} - (HV_{0.5})_{Base\ Metal}}{(HV_{0.5})_{Base\ Metal}} \qquad (3.1)$$

of the AHSS CP-W800 and MS-W1200 as well as of the mild steel DC01 are given in *Figure 10*. One can see how the hardness acts depending on the different materials. The hardness difference becomes greater when the strength of the material is lower.

Generally, the influence of the welding current form on the hardness is of special interest. It has been shown [12] that a lot of current forms without special requirements have no influence on the hardness. But by optimizations procedures due to the preheating and post-heating time it is possible to influence the hardness behavior in the HAZ and the weld nugget.

Also the welding current form, e. g. AC or DC current, has an influence on the hardness of the weld nugget. *Figure 11* shows by an example of RA-K40/70 the hardness traverse of two weld nuggets produced by a welding gun using AC and DC current. It can be seen that the nugget welded by DC current exhibits a significantly lower hardness, i. e. it is reduced by an amount of approx. 50 HV 0.5.

For the uncoated AHSS RA-K40/70 and CP-W800 and the mild reference steel DC01, tensile-shear tests of spot welded tension-shear test specimens were carried out according to EN ISO 14273. The results of tests are given in *Table 6*.

Material		Welding parameter			Quality features		
	t [mm]	t_W [cyc.]	F_e [kN]	I [kA]	d [mm]	F_s [kN]	Type of fracture
DC01	1.50	10	3.0	8.2	6.5	11.39	plug failure
		10	2.2	7.0	6.1	10.21	
		20	2.2	6.9	6.7	11.96	
		20	3.0	8.3	7.9	12.22	
RA-K 40/70	1.60	10	3.5	6.7	6.3	18.66	plug failure
		10	5.5	8.0	7.4	18.98	
		20	3.5	7.0	7.1	23.48	
		20	5.5	8.0	8.7	23.05	
CP-W 800	1.65	10	4.5	7.8	7.0	26.18	plug failure
		10	5.5	8.5	7.3	27.09	
		20	3.5	7.6	7.8	30.32	
		20	5.5	8.3	8.5	31.59	

Table 6: Welding parameters and quality features for single spot weld specimens

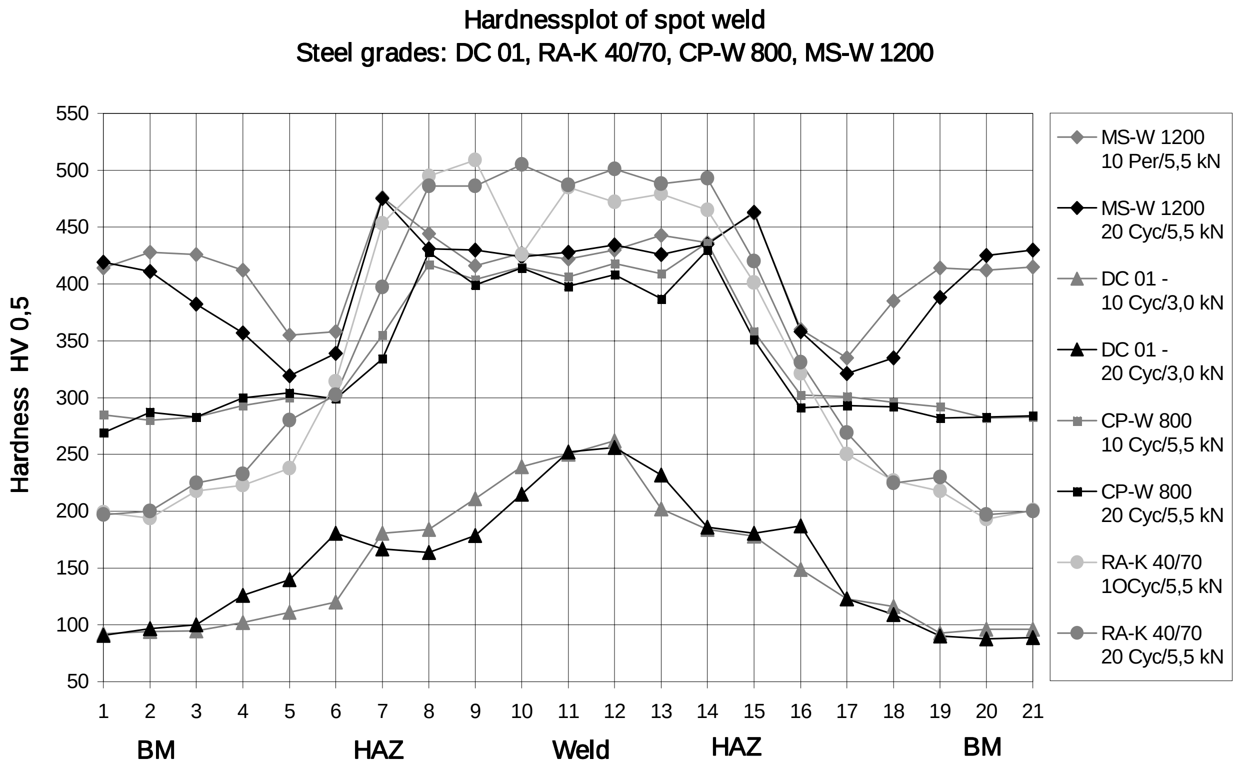


Fig. 9: Variation of hardness across the spot welds of different steel grades welded by a stationary machine (50 Hz)

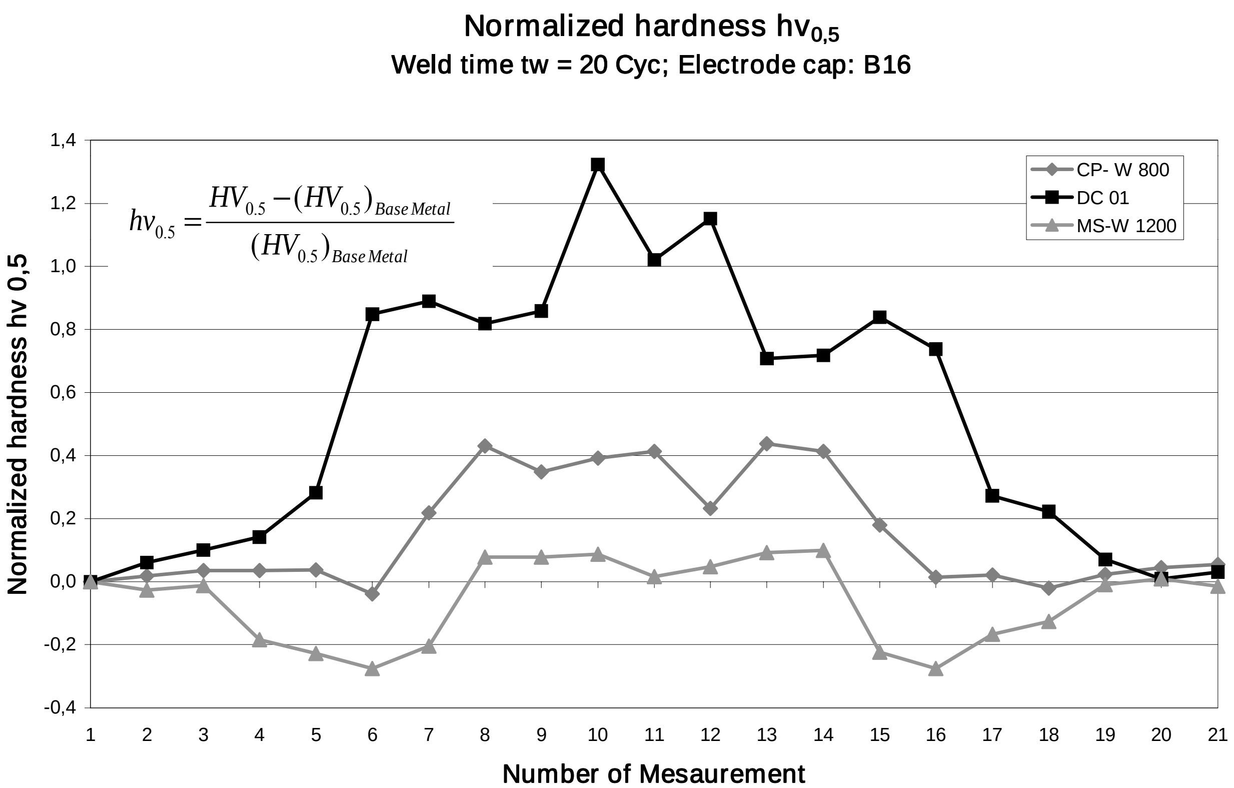


Fig. 10: Normalized hardness across the spot welds of different steel grades welded by a stationary machine (50 Hz)

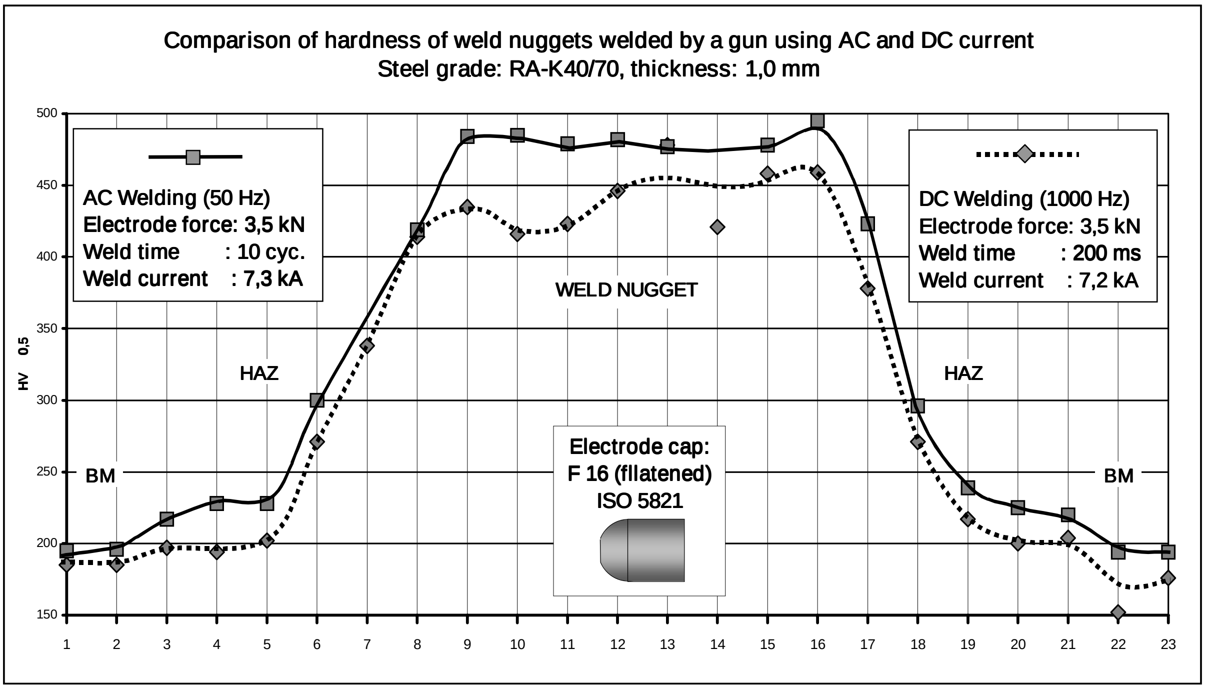


Fig. 11: Comparison of hardness of weld nuggets welded by a gun using AC an DC current steel grade: RA-K40/70, thickness: 1.0 mm

The test specimens were welded by a AC welding gun with electrode caps of the type B16. The type of fracture in all cases was a plug failure. The possibility of other failure types (interface failure or partial plug failure) depends on the test procedure. Clearly, in torsion testing, interface failures will be the predominant type of failure. But in the other test procedures (tensile-shear, fatigue testing etc.), plug failures and partial plug failures are the significant failure types. The results given in *Table 6* show the influence of the welding parameters F_e and t_w on the quality features tensile-shear force F_s and weld diameter d. Some of these results are depicted in *Figures 12 - 13*.

In particular, *Figure 12* shows the influence of the welding time on the weld diameter. The influence of the welding time on the tensile-shear force is represented in *Figure 13*. Both the tensile-shear force F_s and the weld diameter d increase when the welding time t_w. is prolonged. Therefore, a significant difference of the quality features with regard to medium– or long-time welding was found. This means that both the quality features tensile-shear force and weld diameter show the same behavior with respect to the process reliability as shown in Chapter 3. From *Table 6* also follows the influence of electrode forces on the quality features tensile-shear force and weld diameter. But this influence is not as significant as in the case of welding time [10-11].

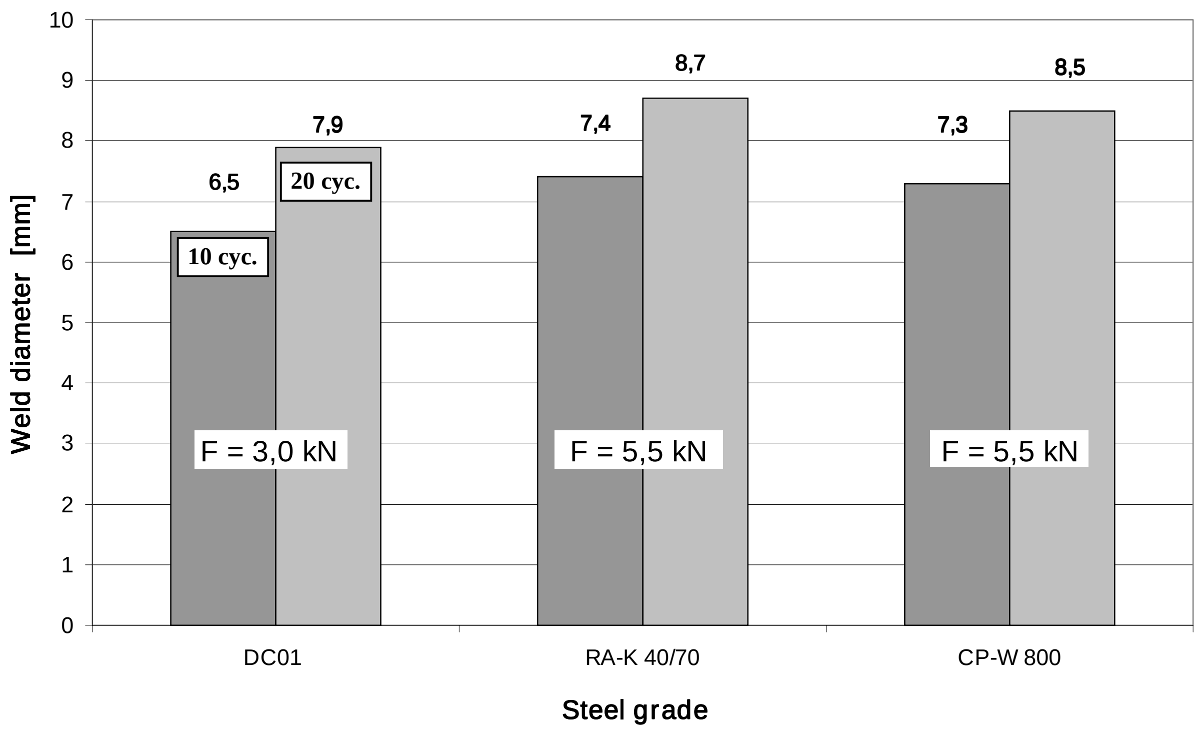


Fig.12: Weld diameters of spot welds of different steel grades

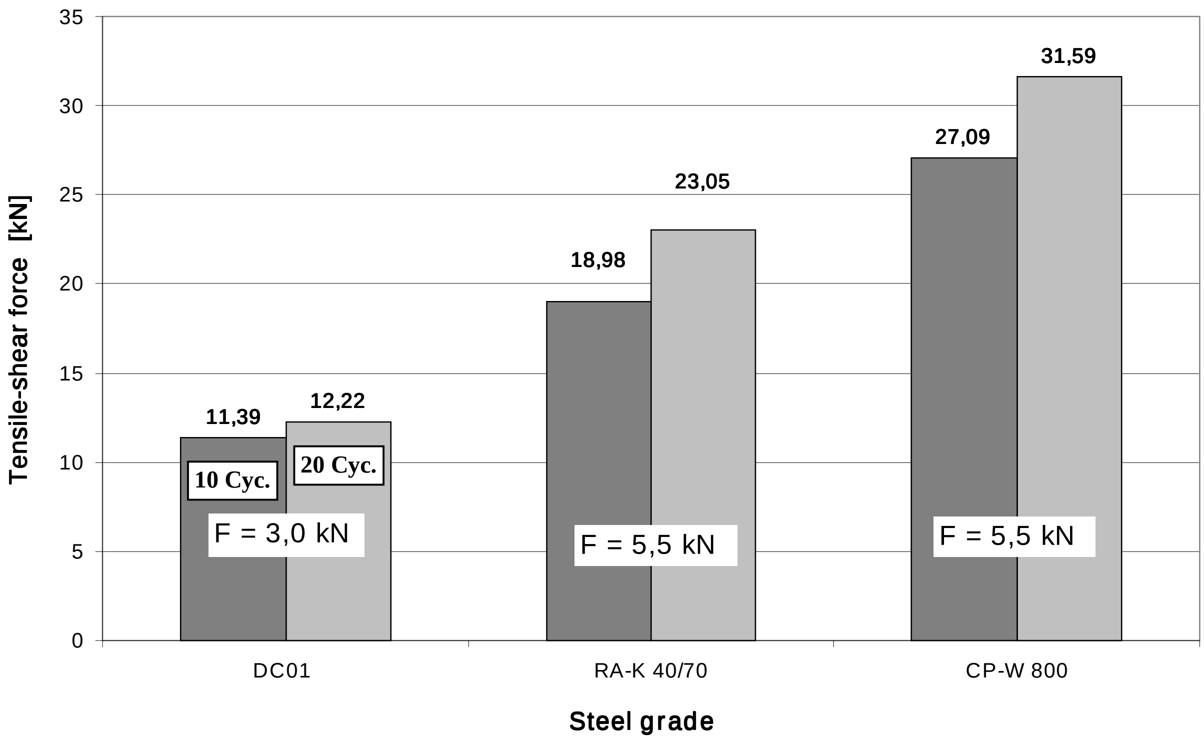


Fig.13: Tensile-shear force of spot welds of different steel grades

For the uncoated AHSS RA-K40/70, CP-W800 and MS-W1200 and for the uncoated mild reference steel DC01, fatigue tests were carried out. This was done for tensile-shear specimens using tensile-fatigue test procedures according to EN ISO 14324. The specimens used were welded by an AC welding gun with electrode caps of the B16 type. For each of the four steel types, different welding parameters were applied, *Table 7*.

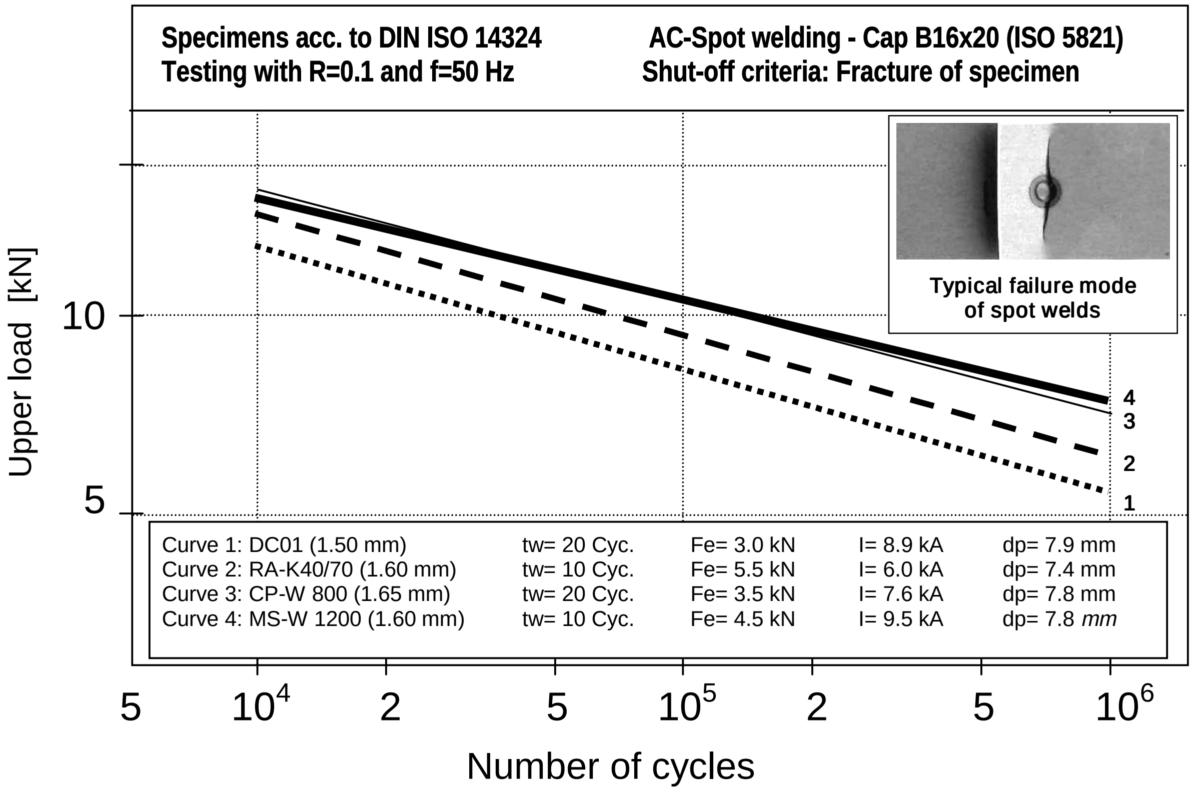
	Welding parameter			Quality features		
Material	t_W [cyc.]	F_e [kN]	I [kA]	d [mm]	F_S [kN]	Type of fracture
DC 01	20	3.0	8.3	7.9	12.22	plug failure
RA-K 40/70	10	5.5	8.0	7.4	18.98	plug failure
CP-W 800	20	3.5	7.6	7.8	30.32	plug failure
MS-W 1200	10	4.5	9.5	7.8	31.35	plug failure

Table 7: Welding parameters for fatigue tests

The Wöhler tests were carried out by a servo-hydraulic test system under force-controlled regime with a load ratio of R = 0.1 and a test frequency of f = 50 Hz. Each of the S-N curves (Wöhler curves) is based on 7 to10 test specimens. The test stop criterion was the total fracture of the weld joints. In this connection, plug failures or fractures in the material were the dominating failure types. Weld diameter was used as the criterion for comparing the fatigue test results from the different steel types. The value of the weld diameter was nearly 7.8 mm in all cases, *Table 7*. The results of the Wöhler tests are given in *Figure 14*. The results show that for all tested AHSS, the number of cycles is higher than in the case of the reference material DC01. In particular, the numbers of cycles of the complex phase steel CP-W800 and of the martensite phase steel MS-W1200 are significant higher than in the case of reference steel DC01 and higher than in the case of TRIP steel RA-K40/70. For example, for the test force of 4.0 kN we have the maximum numbers of cycles (total fracture):

- 68473 for DC01 (reference steel)
- 184700 for RA-K40/70 (TRIP steel)
- 255044 for CP-W800 (complex phase steel)
- 314771 for MS-W1200 (martensite phase steel)

Similar results for other tests forces follow according to the tables in *Figure 14*. It can be summarized that the maximum numbers of cycles of the AHSS are higher than the maximum number of cycles of the mild reference steel. Thus, the fatigue life of the tested AHSS is higher than that of the tested mild reference steel.



DC01		
Specimen Number	Upper load Fo [kN]	Number of cycles to failure
46_7	6,0	24393
46_8	5,5	18171
46_9	5,0	39387
46_10	4,5	42498
46_11	4,0	68473
46_14	3,7	119408
46_12	3,5	267753
46_13	3,0	408639
46_16	2,7	271954
46_15	2,5	640709

RA-K 40/70		
Specimen Number	Upper load Fo [kN]	Number of cycles to failure
80-8	7,0	17063
80-9	6,5	25051
80-10	6,0	35623
80-11	5,5	48081
80-12	5,0	81084
80-13	4,5	110672
80-14	4,0	184700
80-15	3,5	337128
80-17	3,0	554577
80-18	2,7	717451

CP-W 800		
Specimen Number	Upper load Fo [kN]	Number of cycles to failure
117-17	7,0	30086
117-18	6,5	34322
117-19	6,0	43537
117-20	5,5	71473
117-21	5,0	382570
117-22	4,5	159230
117-23	4,0	255044
117-24	3,5	run-through

MS-W 1200		
Specimen Number	Upper load Fo [kN]	Number of cycles to failure
48_16	7,0	18056
48_9	6,5	45615
48_15	6,0	56387
48_14	5,5	150521
48_13	5,0	195944
48_12	4,5	168756
48_10	4,0	314771
48_11	3,5	903735

Fig. 14: Wöhler curves of spot welds of approx. same weld diameter welded with different parameters

6 Conclusions

For given welding parameter combinations, welding ranges (WCR) for different multi-phase steels were developed. In this connection three-dimensional weldability lobes for TRIP steel, complex phase steel and a mild reference steel were established. From these weldability lobes, the influence of short-, medium- and long-time welding and of different values of electrode force on the process reliability can be concluded. Depending on the welding parameters, there exist sufficiently high process reliabilities for the investigated AHSS. For uncoated steel sheets, however, the biggest WCR and therefore the highest process reliabilities was found. In the case of hot dip zinc coated steel sheets, sufficiently high process reliabilities will be realized by optimization of the two welding parameters electrode force and welding time. Only in the case of practically unimportant short-time welding a process reliability does not exist. But in the mass production of automobiles, usually medium- and long-time welding is used. Therefore, for sufficiently high electrode forces in all situations of car mass production, there exist always sufficiently high process reliabilities which guarantee spot welds of high quality. It is well known that the process reliabilities with middle frequency inverter welding guns are higher than with AC welding guns /6, 7/. Therefore, the process reliabilities found in this study would become higher using middle frequency inverter welding guns. Because of the existence of process reliabilities for given welding parameters and a sufficiently high electrode life both in the case of uncoated and hot dip zinc coated high-strength multi-phase steel sheets, the weldability of the tested steels is guaranteed.

Depending on the test procedure, different types of failures occur in the case of AHSS. E. g. in the case of torsion test, interface failures are dominant. For other test procedures like the tensile-shear test or the fatigue test with tensile-shear loading, partial plug failures or plug failures are dominant.

The quality features tensile-shear force and weld diameter are significantly influenced by the welding time. The influence of electrode force on these features is negligible.

The maximum numbers of cycles of the tested AHSS is higher than the maximum numbers of cycles of the tested mild reference steel. Thus, the fatigue life of the tested AHSS is higher than the fatigue life of the tested mild reference steel.

In sum, this contribution has shown that process reliability, weldability, acceptable fracture behavior, high static strengths and high fatigue lives can stated for the tested AHSS when applying the appropriate spot welding technique.

References:

[1] N. N.: Ultra light steel auto body final report. American Iron and Steel Institute, Washington D. C./USA 1998

[2] Osburg, B., Patberg, L., Grüneklee, A., Flöth, Th., Große-Gehling, M., Hinz, M., Mebus, H.: New Steel Body – Sicherer und wirtschaftlicher Karosserieleichtbau mit Stahl, Automobiltechnische Zeitschrift ATZ 3/2004, Jahrgang 106, S. 190.

[3] N. N.: Proceeding of the Conference “State-of-the-Art Multi-Phase Steels”. 23./24. September 2004, Berlin (Germany).

[4] Weber, G. and Göklü, S.: „Resistance spot welding of advanced high strength steels – Influence of welding parameters and electrode cap type“. International Conference of the International Institute of Welding (IIW), Prague, Czech Republic, 14-15 July 2005.

[5] ISO/DIS 14327 “Resistance welding – Procedures for determination the weldability lobe
for resistance spot, projection and seam welding” (Ausgabe November 2000)

[6] Weber, G., u. a.: Schweißbereichsdiagramme – Instrumente zur Qualitätssicherung beim Widerstandspunktschweißen; DVS-Bericht 213, S. 46/52; DVS-Verlag, Düsseldorf 2001

[7] Weber, G.: Weldability lobes in resistance spot welding; IIW-Dok. III-1207-02, Kopenhagen 2002

[8] Weber, G. u. Tischlinger, W.: Extended weldability lobes in resistance spot welding; IIW-Dok. III-1250-03, Bukarest/Rumänien 2003.

[9] Weber, G.: Process reliability in resistance spot welding; IIW-Dok. III-1251-03

[10] Weber, G., Göklü, S. und Momeni, K.: Schweißbereiche höchstfester Stahlfeinbleche für den Rohkarrosserie-Leichtbau; Einfluss der Schweißparameter; Schweißen und Schneiden 55/2003, H. 7, S. 566 – 575

[11] Weber, G. und Göklü, S.: Schweißeignung und Prozesssicherheit beim Widerstandspunktschweißen hoch fester Mehrphasenstähle im Rohkarosserie-Leichtbau; EUROJOIN 5, Wien 2004, S. 1; V9/1 - 30

[12] Weber, G., Göklü, S., Tischlinger, W., Momeni, K. und Xu, P.: Widerstandspunktschweißen hoch fester Mehrphasenstähle für den Karosserie-Leichtbau: Schweißbereiche-Prozesssicherheit-Aufhärtung-Festigkeit Tagungsband; zur 19. DVS-Sondertagung; „Widerstandsschweißen 2004“, Duisburg 2004.