

Global Approach on the Shear and Cross Tension Strength of Resistance Spot Welded Thin Steel Sheets

Kornél Májlínger^{1,2*}, Levente T. Katula¹, Balázs Varbai¹

¹ Department of Materials Science and Engineering, Faculty of Mechanical Engineering, Budapest University of Technology and Economics, Bertalan Lajos str. 7., H-1111 Budapest, Hungary

² MTA-BME Lendület Composite Metal Foams Research Group, Bertalan Lajos str. 7., H-1111 Budapest, Hungary

* Corresponding author, e-mail: majlinger.kornel@gpk.bme.hu

Received: 14 August 2023, Accepted: 20 September 2023, Published online: 24 October 2023

Abstract

Several correlations from the professional literature describing the shear and cross tension strength (STS and CTS) of resistance spot welded (RSWed) thin steel sheets were investigated. Some of them need chemical composition or weld nuggets strength hardness as input parameters, making them hardly applicable in the planning stage of the joints. Using STS and CTS data collected from over 250 papers, selected correlations were tested, whether they are applicable to predict the STS and CTS of the RSWed joints at the planning stage to help designers plan their static-loaded welds strength. Most correlations had limitations in the applicable base materials' tensile strength range. Therefore, new equations for STS and CTS are proposed, which can be used to plan in the 300–18900 MPa base metals tensile strength range for similar and dissimilar RSWed joints of thin steel sheets.

Keywords

resistance spot welding (RSW), thin steel sheet, shear tension strength (STS), cross tension strength (CTS)

1 Introduction

Resistance spot welding (RSW) is a prevalent technology for fast joining thin metal sheets. Due to the versatility of the process, it is applicable for various materials from aluminum, copper, or nickel-based alloys and different steel types and material combinations. Depending on the material combinations to be joined, the weldable sheet thickness ranges from thin foils to several millimeter-thick sheets [1].

The most prominent usage of RSW is in the automobile industry, where primarily thin steel sheets need to be welded in various thickness and strength combinations. Thus, different car body parts need different material properties and therefore different steel types. In the automobile industry, there is also a strong strive to save the self-weight of the vehicle to reduce fuel consumption, thus, higher and higher strength steels are used, and need to be welded [2–4]. With the increasing trend towards electric vehicles however, the usage of high strength steels is more pronounced, to compensate the high weight of the battery pack and improve safety and drive dynamics. Therefore, the usage of advanced high-strength steels (AHSSs) or ultra-high-strength steels (UHSSs) is nowadays pretty common in car bodies. Of course, this striving

to reduce self-weight and use high-strength steels is also present in many different industry branches [5–8].

To produce sound parts high quality spot welds are needed. There are a lot of standardized and non-standardized testing methods to qualify and quantify the soundness of the joints, like shear tension, cross tension, coach peel, fatigue, and also different dynamic tests [1].

For design purposes at least some strength values should be estimated beforehand. Therefore, in our work we try to find some prediction models to estimate the shear tension strength (STS) and the cross tension strength (CTS) for static-loaded joints to help designers at the planning stage of the RSWed joints.

2 Literature research

There are lots of works in the literature for RSW of steel, where the different mechanical properties of the joint were investigated. Some correlations were found between the properties of base materials or weld materials (e.g., hardness, tensile strength etc.) and the different joint strength types (e.g., STS, CTS, coach peel strength, etc.). Most are developed for a narrow range of steel types in thickness,

chemical composition, or tensile strength. Those empirical correlations for STS and CTS will be investigated here to determine whether they are applicable in the planning stage of RSWed joints strength if only the desired base material strength and the thickness is known.

2.1 Prediction of the shear tension strength

In the literature, there are several types of research to predict the achievable STS of the RSWed steel joints.

Heuschkel [9] investigated more than 4000 RSWed joints of manganese alloyed plain carbon steels in different sheet thicknesses. He made a mathematic model for predicting the STS Eq. (1)¹,

$$STS(\text{lb}) = t \cdot d \cdot R_m \cdot (\alpha - \beta \cdot (C + 0.05 \cdot \text{Mn})) \quad (1)$$

where t is the sheet thickness (here in inch), d is the weld nugget diameter (here in inch), R_m is the base materials tensile strength (here in psi), α (1.5–3.5), and β (0.5–4.5) (depending on the sheet thickness) are components of shear tension strength formulas without dimension and C, Mn are the carbon and manganese content in mass %. The correlation worked well in the investigated R_m range 320–880 MPa and sheet thickness (0.2–12.7 mm) and chemical compositions in the range of $0.01 < C\% < 0.58$ and $0.29 < \text{Mn}\% < 0.87$. But obviously, previous knowledge of chemical composition is needed to be able to use this function.

Sawhill and Baker [10] found a simple equation (Eq. (2)) for re-phosphorized steel for a low R_m range (350–550 MPa),

$$STS = A \cdot t \cdot d \cdot R_m \quad (2)$$

where A is a coefficient. It was determined $A = 3$, and for low carbon equivalents $A = 2.5$ –3.0. This equation would be a simple tool if there were a narrow range of coefficient A for all steel compositions.

Defourny et al. [11] investigated 1–2 mm thick mild steel and high strength low alloy steel (HSLA) and developed their correlation for STS (Eq. (3)). This correlation is promising and thus does not consider the chemical composition, only the base metals' strength and sheet thickness.

$$STS(\text{daN}) = 9.5 \cdot t^{1.26} \cdot R_m^{0.76} \quad (3)$$

Many researchers compared the different type of joint failure under shear-tensile load. For shear type or interfacial fracture e.g., [12, 13] (Eq. (4) and Eq. (5)), [14] (Eq. (6)), and [15] (Eq. (7)),

$$STS = B \cdot 2 / \sqrt{3} \cdot \pi \cdot d^2 / 4 \cdot R_{m \text{ nugget}} \quad (4)$$

$$STS = 9.8 \cdot \pi \cdot d^2 / 4 \cdot HV_{\text{nugget}} / 3^{1.5} \quad (5)$$

$$STS = D \cdot d^2 \cdot R_m \quad (6)$$

$$STS(\text{daN}) = 1.1 \cdot d^2 \cdot HV_{\text{nugget}} \quad (7)$$

where $R_{m \text{ nugget}}$ and HV_{nugget} are the weld nuggets tensile strength and Vickers hardness, respectively. B and D are coefficients $D \sim 0.6$. In most engineering applications, interfacial fracture of the weld nugget is to be avoided. Therefore, these correlations were not investigated in detail. Another difficulty with Eqs. (4)–(6) is that $R_{m \text{ nugget}}$ and HV_{nugget} are measurable but hardly predictable in the planning stage. Some models are developed for their prediction (e.g., [16–21]), mostly based on the chemical composition of the base material, but their usage is limited to selected steel groups.

Kuo and Chiang [22] investigated steel grades in $400 \text{ MPa} < R_m < 1000 \text{ MPa}$ strength range, and for interfacial fracture they proposed a correlation; where STS is proportional with the weld nugget size, the hardness ratio between nugget and base material ($\text{Hard.} = HV_{\text{nugget}} / HV_{\text{BM}}$) and the shear strength of the base material (Eq. (8)).

$$STS = \text{Hard.} \cdot d^2 / 4 \cdot \tau_m = HV_{\text{nugget}} / HV_{\text{BM}} \cdot d^2 / 4 \cdot \tau_m \quad (8)$$

Where HV_{BM} is the base materials Vickers hardness and τ_m is the shear strength of the base material.

Of course, as mentioned earlier the favorable failure type for most engineering applications under shear load is the plug type or pull-out fracture, there are several equations for that as well.

Oikawa et al. [12, 13] found the same equation as Eq. (2) to be applicable and other correlations too (Eqs. (9)–(12)).

$$STS = E \cdot t \cdot d_{\text{plug}} \cdot R_m \quad (9)$$

$$STS = F \cdot t^{1.26} \cdot R_m^{0.76} \quad (10)$$

$$STS = 36.4 \cdot t^{1.42} \cdot R_m^{0.84} \quad (11)$$

$$STS(\text{kN}) = 2.05 \cdot t \cdot R_m \cdot (d + 2.09) \cdot (1 + 0.0059 \cdot \text{El.}) \quad (12)$$

Where E , F are coefficients, d_{plug} is the diameter of the pulled-out plug after pull-out fracture, and El. is the elongation of the base metal sheets. The diameter of the plug is measurable, but the prediction is hardly applicable. Also, the elongation of the selected steel group is might not been known in the planning stage of the welded part, therefore Eq. (9) and Eq. (12) will not be investigated further.

¹ Note for the other formulas if not indicated otherwise SI units are used STS is given in N, t and d in mm, R_m in MPa.

Equation (10) and Eq. (11) donot consider the weld nugget size, but they could be easy to use for planning.

Sakuma and Oikawa [23] and Sakuma et al. [24] also proposed a correlation for STS either from the weld nugget strength and size (Eq. (13)),

$$STS = G \cdot \pi \cdot d^2 / 4 \cdot R_{m \text{ nugget}} \quad (13)$$

where G is a constant. The investigated steels were in the $R_m = 400\text{--}800$ MPa strength range and $t = 1\text{--}2.6$ mm thick. Again, the weld nuggets strength is hard to forecast, therefore this correlation is hardly applicable in the planning stage. They also investigated Eq. (2) and determined factor $A = 2.5\text{--}3.3$, and found it is also dependent on the sheet thickness, base materials' strength, and the chemical composition mainly the carbon and silicon content, which makes the application of a relatively simple correlation a lot more complicated.

Radakovic and Tumuluru [14] and Tumuluru [25] investigated the spot welds strength of various steel types (interstitial free (IF), dual phase (DP), and transformation induced plasticity (TRIP) steels) in the $R_m = 300\text{--}880$ MPa strength range in $t = 1\text{--}1.6$ mm thicknesses. They found for pull-out fracture mode Eq. (2) to be sound with $A = 2.2\text{--}2.25$.

There are of course, standardized correlations for the minimum acceptable STS for uncoated and coated low carbon steels, e.g., International Organization for Standardization (ISO) and British standards (BS). Both the ISO 14373:2015 [26] and the BS 1140:1993 [27] standard requires a minimum STS according to Eq. (2) where $A = 2.6$. The BS 1140:1993 standard [27] also gives correlations for dissimilar joints according to Eqs. (14)–(16),

$$\text{if } t_1 < t_2 < 2.5 \cdot t_1 \quad STS = 2.7 \cdot \sqrt{t_1} \cdot d \cdot R_{m1} \quad (14)$$

$$\text{if } t_2 > 2.5 \cdot t_1 \quad STS < 0.691 \cdot d^2 \cdot R_{m1} \quad (15)$$

$$\text{if } t_2 > 2.5 \cdot t_1 \quad STS < 3.08 \cdot t_1 \cdot d \cdot R_{m1} \quad (16)$$

where t_1, t_2 are the thicknesses and R_{m1}, R_{m2} are the tensile strength of the steel sheets.

These listed equations (Eqs. (1)–(16)) give their correlation mostly in the $R_m < 900$ MPa strength range, but the newly developed AHSS and UHSS grades can have more than two times this tensile strength. The AWS D8.1M:2013 standard [28] made for automotive applications fills this gap and gives a correlation for the minimum acceptable STS (Eq. (17)). Equation (17) already covers the whole strength range from normal strength steels till AHSSs.

There is one interesting property though, namely above 1340 MPa R_m the required STS values start to decrease.

$$STS = (-6.36 \cdot 10^{-7} \cdot R_m^2 + 6.58 \cdot 10^{-4} \cdot R_m + 1.674) \cdot R_m \cdot 4 \cdot t^{1.5} \quad (17)$$

Previously the authors [29] analyzed STS data from approx. 80 papers in the professional literature, and found, that this decrement in the STS values in the UHSS range is not necessarily right (at least not that severe) and proposed a new correlation above 1340 MPa base materials tensile strength (Eq. (18)).

$$STS = \left[3788.77 - \left(\frac{-6.36 \cdot 10^{-7} R_m^2}{+6.58 \cdot 10^{-4} \cdot R_m} \right) \cdot R_m \right] \cdot 4 \cdot t^{1.5} \quad (18)$$

This was a basic concept, which increased the STS values of the AWS D8.1M:2013 standard [28] with the same amount as it was below its maxima (at $R_m = 1340$ MPa). After extended literature and experimental research, data of approx. 160 papers were analyzed [30] and a prediction for the STS values was given in a wide tensile strength range ($R_m = 400\text{--}2000$ MPa), for thin steel sheets ($t = 0.3\text{--}4$ mm) (Eq. (19)). This correlation suggests that STS keeps increasing in the whole R_m range even if $R_m > 1340$ MPa. The comparison between the Eq. (1) according to Radakovic and Tumuluru [14] and Tumuluru [25], according to the ISO standard [26] and the Eq. (18) according to the AWS standard [28] was also presented here [30].

$$STS(\text{kN}) = -10.10 + 15.80 \cdot t + 0.0088 \cdot R_m \quad (19)$$

Xu et al. [31, 32] conducted many experiments in a wide tensile strength range of $R_m = 250\text{--}1600$ MPa steel, $t = 0.6\text{--}1.6$ mm thickness in similar and dissimilar combinations. They made a standardized shear strength function which multiplied with the sheet thicknesses (Eq. (20)) gave a good correlation with their experimentally measured STS values. According to this function (Eq. (20)), STS monotonously increases in the UHSS range too:

$$STS = t_1 \cdot t_2 \cdot \left(\frac{8 \cdot 10^{-9} \cdot R_{m1}^3 - 3 \cdot 10^{-5} \cdot R_{m1}^2}{+0.0418 \cdot R_{m1} - 6.0904} \right), \quad (20)$$

where $R_{m1} < R_{m2}$. Note that besides the Eqs. (14)–(16) of the BS 1140:1993 standard [27] this is the only correlation easily applicable for dissimilar joints. While, the British standard relies on the thinner sheet thickness, Eq. (20) relies on the weaker base material of the two sides of the weld.

Of course, the other equations also can be used for dissimilar welds. Here, it is recommended to calculate the

STS according to both sides of the joint and use the smaller value for designing the welded part.

2.2 Prediction of the cross tension strength

To prepare cross tension specimen and measure their strength is a little bit more complicated, maybe that's why there are fewer formulas to forecast the cross tension strength of RSWed joints, than for STS.

Heuschkel [9] also investigated the CTS of the carbon and manganese alloyed steels (Eq. (21))².

$$CTS(\text{lb}) = t \cdot d \cdot R_m \cdot \left[a / (R_m - b) + c - (f \cdot C + g \cdot \text{Mn}) \right] \quad (21)$$

Where t is the sheet thickness (here in inch), d is the weld nugget diameter (here in inch), R_m is the base materials tensile strength (here in psi), a and b components of normal strength formulas in psi, c , f and g components of normal strength formulas without dimension and C , Mn are the carbon and manganese content in mass %. The problem here is the same, as with their STS formula (Eq. (1)), namely previous knowledge of chemical composition is needed to be able to use this function, and its limited R_m and chemical composition range.

There are other formulas from Oikawa et al. [12, 13] for shear type fracture based on the weld nuggets' mechanical properties (hardness and tensile strength) (Eq. (22) and Eq. (23)),

$$CTS = H \cdot \pi \cdot d^2 / 4 \cdot R_{m \text{ nugget}} \quad (22)$$

$$CTS = 9.8 \cdot \pi \cdot d^2 / 4 \cdot (1.4 - 0.003 \cdot HV_{\text{nugget}}) \cdot (HV_{\text{nugget}} / 3) \quad (23)$$

where H is a coefficient.

Kuo and Chiang [22] proposed for interfacial fracture too, to use the hardness ratio in their equation (Eq. (24)).

$$CTS = \text{Hard.} \cdot \pi \cdot d^2 / 4 \cdot R_m = HV_{\text{nugget}} / HV_{\text{BM}} \cdot \pi \cdot d^2 / 4 \cdot R_m \quad (24)$$

Equations (22)–(24) are hard to use thus as already mentioned the weld metals' hardness and tensile strength are hard to predict in the planning stage. Of course, in the case of the cross tension (normal) load, the favored fracture type is the pull-out fracture. Therefore, these correlations were not investigated in detail.

For the preferred pull-out fracture Oikawa et al. [12, 13] proposed Eqs. (25)–(27)). In the planning stage Eq. (26)

is the handiest, thus only the sheet thickness and nugget size is needed.

$$CTS = I \cdot 2 / \sqrt{3} \cdot \pi \cdot t \cdot d \cdot R_{m \text{ nugget}} \quad (25)$$

$$CTS = 645 \cdot t \cdot d^{1.27} \quad (26)$$

$$CTS = 5 \cdot \pi \cdot t \cdot d \cdot R_{m \text{ nugget}} \cdot [1 - 100 / (100 + 0.5 \cdot \text{El.})]^{1.46} \quad (27)$$

Sakuma and Oikawa [23] and Sakuma et al. [24] proposed a similar correlation (Eq. (28)) for the CTS as Eq. (2) for the STS values.

$$CTS = J \cdot t \cdot d \cdot R_m \quad (28)$$

Where J is a coefficient. The investigated steels were in the 400 MPa < R_m < 800 MPa strength range and $t = 1$ –2.6 mm thickness range. They determined, $J = 1.2$ –2.7 of and found it is dependent on the sheet, thickness, base materials' strength and the chemical composition, mainly the carbon and silicon content.

Kuo and Chiang [22] proposed a correlation for pull-out fracture too. They used the hardness ratio in their equation as well (Eq. (29)).

$$CTS = \text{Hard.} \cdot \pi \cdot t \cdot d \cdot \tau_m = HV_{\text{nugget}} / HV_{\text{BM}} \cdot \pi \cdot t \cdot d \cdot \tau_m \quad (29)$$

As for the standardized correlations, the AWS D8.1M:2013 standard [28] gives the minimum acceptance criteria for automotive applications for CTS values too (Eq. (30)).

$$CTS = 1.25 \cdot t^{2.2} \quad (30)$$

Here again, the only parameter is the steel sheets thickness.

The equations for calculating CTS (Eqs. (21)–(30)) also can be used for dissimilar welds, here it is recommended to calculate the CTS according to both sides and use the smaller value for designing the welded part.

2.3 Other possibilities of strength prediction

Naturally, correlations get better and better, the narrower the sheet thickness and material range e.g., Rajarajan et al. [33] predicted very accurately the STS, CTS, HV_{nugget} values of RSWed DP800 steel sheets. Good estimations can be made with numerical [34–38] and finite element (FEM) simulations [39–43], machine learning [44], and artificial neural networks [45–48]. These methods can be a very useful and accurate tools to optimize and predict weld properties (STS and CTS as well), but they are primarily applicable to a specific narrow

² Note for the other formulas if not indicated otherwise SI units are used CTS is given in N, t and d in mm, R_m in MPa.

application area, not to a wide range of material strength classes and combinations.

Therefore, these methods are used not in the planning stage of the RSWed parts, but more likely in the optimization of the joint and in whilst establishing an applicable parameter window for production and during quality control by monitoring of the manufacturing process.

2.4 Data collection and processing

In the main scientific databases (e.g., Science Direct, Web of Science, J-Stage etc.) keyword-based searches were run to find possible papers with STS or CTS data. Also, complementary searches were made in specifically welding related journals (e.g., Welding in the World, Welding Journal, Quarterly Journal of the Japan Welding Society, Hegesztéstechnika etc.). The keywords were: resistance spot welding, steel and if available the different joint strengths. Papers mostly in English and Hungarian were processed but also in Japanese and Korean if the figures/tables and their captions were presented in English. STS and CTS data were collected if at least the sheet thicknesses and base materials strength could be determined from the manuscript. If available complementary data, like nugget size, absorbed energy, and scatter for those was also collected. To avoid excess and mostly bad data points, only the STS or CTS data were collected, corresponding to an optimized joint (highest STS or CTS).

To investigate the effectiveness of the concrete correlations, the normalized STS or CTS values for the given equations ($STS_{\text{measured}}/STS_{\text{equation}}$ or $CTS_{\text{measured}}/CTS_{\text{equation}}$) are calculated in Excel® software. The diagrams were made with Origin® software. In case of the dissimilar joints the STS or CTS values were calculated for both sides for the joints – and if the given correlation did not specify otherwise – the value for the weaker side was used for the calculation of the normalized values. For better visualization of the trends of the different equations linear regression using least squares method was made also with Origin® software on most of the plots.

3 Results and discussion

From the listed correlations (Eqs. (1)–(30)) some are harder some are easier applicable in the design stage of the RSWed parts, STS and CTS data of couple hundred papers was collected and evaluated according to the selected equations to see their feasibility for predicting the STS or CTS values in a wide base metals range.

3.1 Evaluation of the STS correlations

From the listed equations for the STS values (Eqs. (1)–(20)) some could be already used in the design stage for shear-tensile loaded RSWed joints. Of course, interfacial fracture is to be avoided. If the concrete material is not yet known for the part to be welded, only the equations which require tensile strength and thickness (Eqs. (2), (3), (10), (11), (14) and Eq. (20)) can be applied, therefore the literature data for those correlations was evaluated. STS data from more than 240 papers was analyzed. The STS values from the professional literature for the optimized joints are plotted in Fig. 1 [12–17, 23, 25, 29, 31–35, 38–40, 45, 47, 49–273]. The dissimilar joints were depicted as the "weaker side" of the joint according to the requirement (Eq. (17)) of the AWS D8.1M:2013 standard [28].

The measured STS values vs. the sheet thicknesses are plotted on Fig. 2. According to this diagram, the STS values increase significantly with the sheet thickness, but the scatter is really high, e.g., for a steel sheet thickness of 2 mm the measured STS values were between 10–46 kN. After linear fitting the STS values for 2 mm thick sheets are predicted to be in the very wide range of 16–40 kN (95% prediction band). Therefore, the applicability of such equations where the sheet thickness is the only parameter

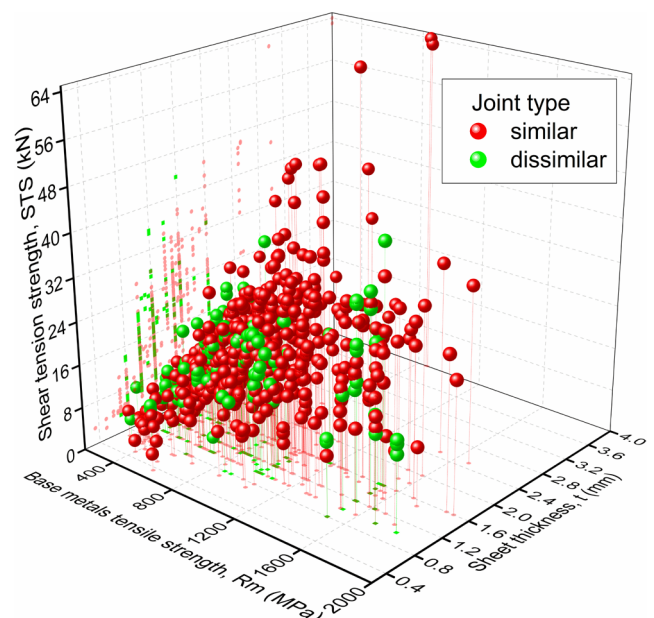


Fig. 1 Graphical representation of the literature data of the STS values is shown in similar [12–17, 25, 29, 31–35, 38, 39, 45, 49–239] and dissimilar [23, 29, 31, 32, 34, 38, 40, 47, 50, 61, 63, 67, 74, 99, 102, 107, 116, 118, 120, 121, 134, 138, 144, 162, 163, 170, 205, 214, 223, 231, 233, 240–273] RSWed joints. For the dissimilar joints, the weaker side is depicted according to Eq. (17).

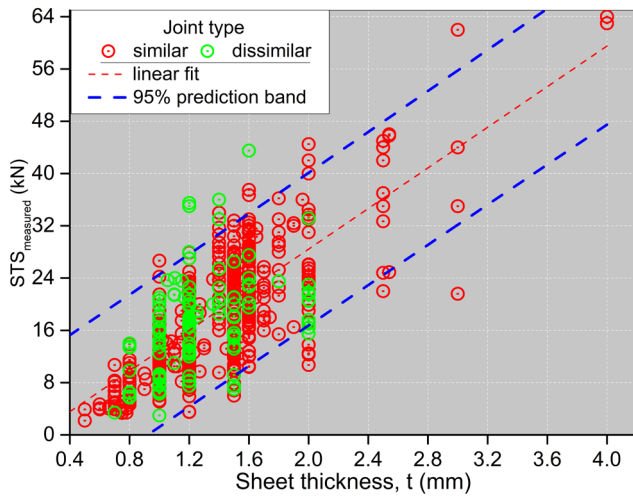


Fig. 2 The measured STS values are shown in similar and dissimilar RSWed joints, for the dissimilar joints, the weaker side is depicted.

for predicting the STS values beforehand seems to be very limited, but they were investigated, nevertheless.

In Fig. 3 the normalized STS values for Eq. (3) is represented in the whole R_m range of $R_m = 300\text{--}1900$ MPa. The normalized STS values are between $\sim 0.3\text{--}1.5$ and scatter asymmetrically around the fitted trend line $+0.4$, and -0.6 at lower R_m and at higher base materials strength it is more pronounced. The normalized STS values are tendentially decreasing in the whole R_m range. Therefore, Eq. (3) is not recommended for designing the joint strength.

Basically Eq. (10) is very similar to Eq. (3), but in [12, 13] factor F was not presented for Eq. (10). Therefore, a parameters search was made via Origin® software on the similar joints STS data. $F = 70.47$ was found to be the best fit (with $R^2 = 0.55$). The normalized STS values for Eq. (10)

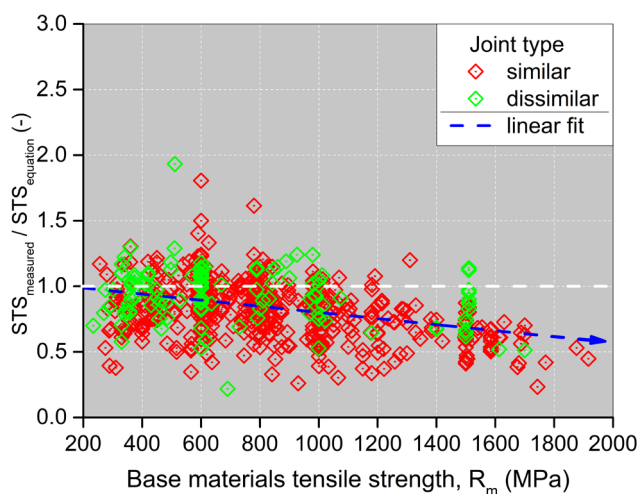


Fig. 3 Normalized STS values are shown according to Eq. (3) for similar and dissimilar RSWed joints, for the dissimilar joints, the weaker side is depicted.

with $F = 70.47$ are in Fig. 4 and they are between $\sim 0.4\text{--}1.7$. This is a bit larger scatter, than in the case of Eq. (3), but the normalized STS values are symmetrically distributed around the fitted line. Moreover, Eq. 10 has the same shortcoming namely, the normalized STS values are tendentially decreasing in the whole R_m range and above $R_m \sim 1200$ MPa it goes below 1. Practically it means that the correlation for lower strength steels overestimates the achievable STS values and for UHSS $R_m > 1200$ MPa it underestimates them. Therefore, Eq. 10 is not recommended for designing the joint strength.

Equation (11) takes the sheet thickness and tensile strength of the material with more weight into account ($t^{1.42}$, $R_m^{0.84}$) compared to Eq. (3) or Eq. (10), which results in a larger scatter in the normalized STS values $\sim 0.5\text{--}2.5$ (Fig. 5). For Eq. (11) too, in the whole base materials tensile Fig. 5 strength range a clear decreasing trend can be observed, and the normalized STS values above $R_m \sim 1300$ MPa fall below 1. Therefore, Eq. (11) is not recommended for designing the joint strength either.

Normalized STS values for the AWS D8.1M:2013 standard [28] can be seen on Fig. 6. In outmost cases the values are above 1, therefore the correlation fulfills its original purpose as a boundary for minimal acceptable STS values. Applying it to the joint strength's planning nevertheless proves to be difficult.

Because as discussed also in [29, 30], the scatter is high $\sim 1\text{--}4$, and due to the nature of Eq. (17), the normalized STS values decrease till $R_m = 1340$ MPa, and then they start to increase again. Therefore, this increment $R_m > 1340$ MPa is somewhat dampened by Eq. (18).

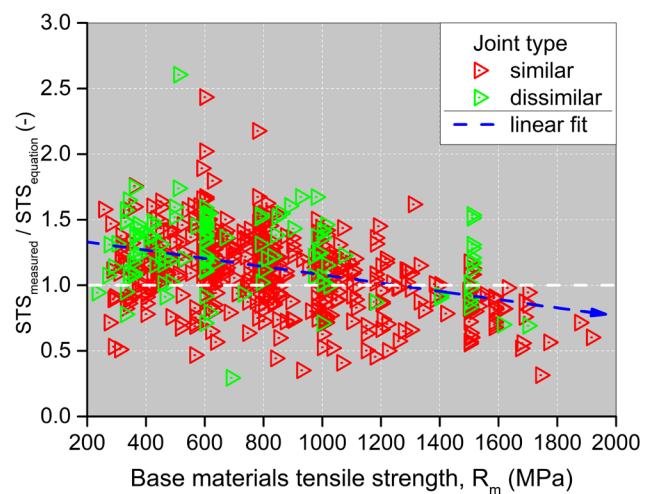


Fig. 4 Normalized STS values are shown according to Eq. (10) with $F = 70.47$ for similar and dissimilar RSWed joints, for the dissimilar joints, the weaker side is depicted.

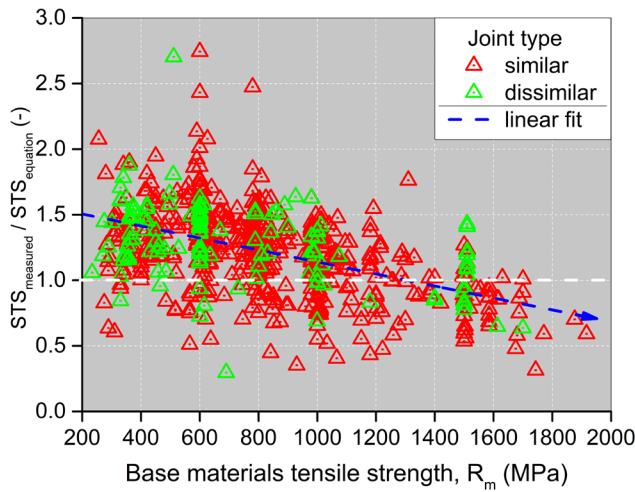


Fig. 5 Normalized STS values are shown according to Eq. (11) for similar and dissimilar RSWed joints, for the dissimilar joints, the weaker side is depicted.

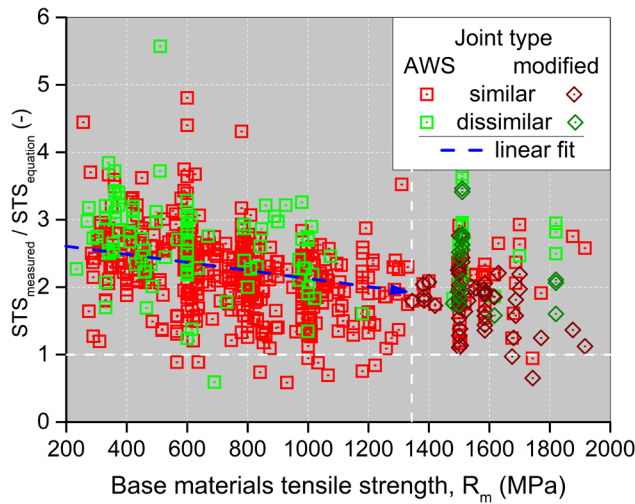


Fig. 6 Normalized STS values are shown according to the AWS standard [28] (Eq. (17)) and modified by the authors [29] when $R_m > 1340$ MPa (Eq. (18)) for similar and dissimilar RSWed joints. For the dissimilar joints, the weaker side is depicted according to Eq. (17) and Eq. (18).

For these reasons, these equations are not recommended for designing the joints strength.

Equations where the nugget size is also a parameter are tricky to use in the planning for the joint strength, but we present a typical approach. According to the literature and also standards (e.g. [1, 274]) to produce sound RSWed joints the weld nuggets diameter should be at least $3.5 \cdot \sqrt{t}$, because below this value different type of weld defects can occur, e.g., lack of fusion, stuck weld etc. The maximum weld nugget size is set typically $5 \cdot \sqrt{t}$ (according to [26]), eventually $6 \cdot \sqrt{t}$, but above this size, other weld defects will occur e.g., splash. Therefore, we will investigate the

correlations where d the nugget size also a parameter is, in the typical region $d = 3.5 - 5 \cdot \sqrt{t}$.

Sawhill and Baker's [10] equation (Eq. (2)), is used by various authors and even in standards [14, 25–27]. The normalized STS values for the two extrema ($A = 2.2$, $d = 3.5 \cdot \sqrt{t}$ and $A = 2.6$ and $d = 5 \cdot \sqrt{t}$) are visualized in Fig. 7 and Fig. 8. It is important to mention that the real nugget sizes maybe differ from the ones assumed in the calculation.

In Fig. 7 there are the normalized STS values, for the smallest STS requirement. These values at small R_m (~ 300 MPa) scatter around $\sim 2.6 \pm 1.4$, and a clear decreasing trend can be observed, the normalized STS values at $R_m \sim 1000$ are in the range $\sim 1.7 \pm 1$. Here in most cases normalized STS values are above 1 (till $R_m \sim 1700$ MPa), but

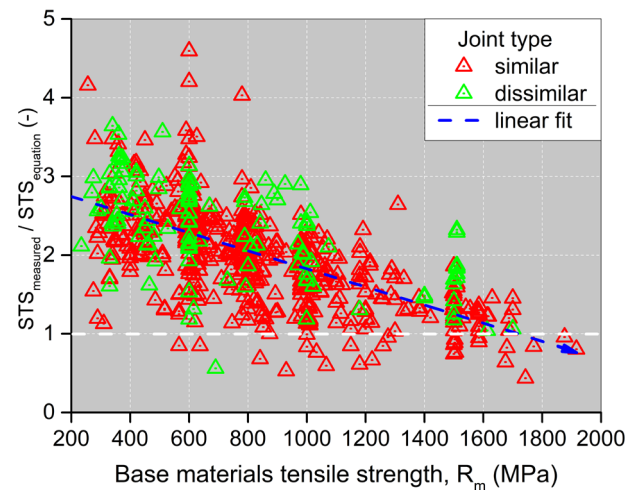


Fig. 7 Normalized STS values are shown according to Eq. (2) where $A = 2.2$ and $d = 3.5 \cdot \sqrt{t}$ for similar and dissimilar RSWed joints. For the dissimilar joints, the weaker side is depicted.

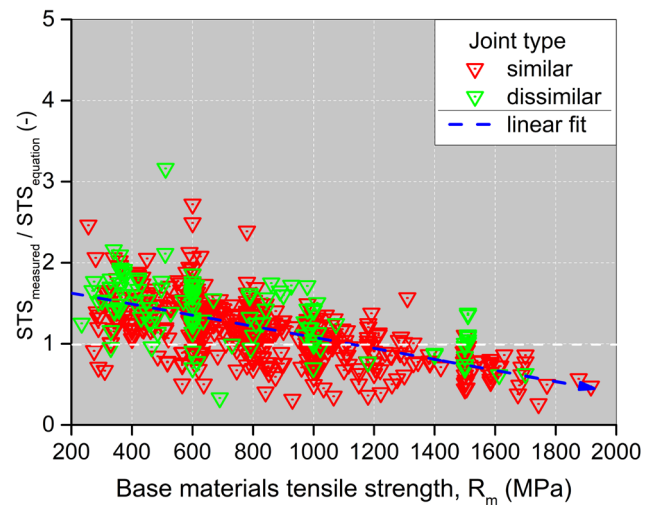


Fig. 8 Normalized STS values are shown according to Eq. (2) where $A = 2.6$ and $d = 5 \cdot \sqrt{t}$ for similar and dissimilar RSWed joints. For the dissimilar joints, the weaker side is depicted.

still more values are below 1 than in the case of Eq. (17) (Fig. 6), therefore as a boundary for minimal acceptable STS values is Eq. (17) a better choice. We have to mention however, that the standardized equation was meant to be used for low carbon steels, and in the UHSS range ($R_m > 800$ MPa) for most steel types, the carbon content also keeps increasing with higher R_m . Therefore Eq. (2) is only recommended to be used to estimate the minimum acceptable STS values for steels $R_m < 800$ MPa, where $A = 2.2$ and $d = 3.5 \cdot \sqrt{t}$, and d is not the actual (measured) nugget size it is only for the calculation.

In Fig. 8 there are the normalized STS values (for the larger STS requirement). If the actual nugget size is not known, $d = 5 \cdot \sqrt{t}$ was used to calculate the minimum acceptable STS of the steels. In the whole R_m range similar decreasing trend can be observed than in Fig. 7. The normalized STS values scatter at low R_m (~ 300 MPa) around 1.5 ± 0.9 but at $\sim R_m = 1200$ MPa these values go below 1. Therefore, for the planning of the joint strength Eq. (2) is not recommended either.

However, in case of similar joints, the British standard [27] uses the same equation as the ISO standard [26], the British standard also gives correlations for the dissimilar joints using the mechanical properties of the thinner side of the joint (Eq. (15) and Eq. (16)). As we can see in Fig. 9 the British Standard gives a little bit smaller normalized STS values in the whole R_m range than the ISO standard. The same decreasing trends can be observed, but the slope of the decrement is smaller in the case of the ISO standard.

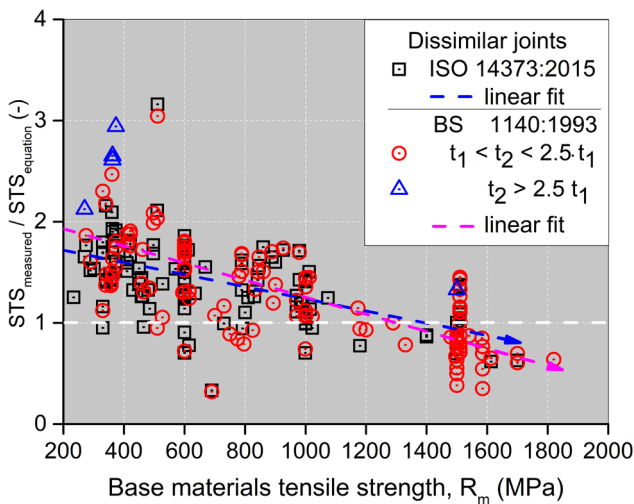


Fig. 9 Normalized STS values of the dissimilar RSWed joints are shown according to the ISO 14373:2015 standard [26], where $A = 2.6$ and $d = 5 \cdot \sqrt{t}$ are used by Eq. (2), and the weaker side is depicted. Normalized STS values of the dissimilar RSWed joints are shown according to the BS 1140:1993 standard [27], where $d = 5 \cdot \sqrt{t}$ is used by Eq. (15) and Eq. (16), and the weaker side is depicted.

The normalized STS results of Xu et al. [31, 32] approach (Eq. (20)) using the smaller R_m of the two base materials is visualized in Fig. 10. The normalized values are mostly in ~ 0.3 – 1.5 range, at lower tensile strength it's a bit more (~ 0.3 – 2.0). Overall, the normalized STS values scatter around $\sim 0.9 \pm 0.6$ and no significant decreasing trend can be observed. Therefore, with a safety factor ~ 3 this correlation could be used globally to predict the STS values.

Previously [30] a plane was fitted on the optimized STS values (similar joints) depending on the base materials' tensile strength and sheet thickness (Eq. (19)). This was done based on STS data of approx. 160 papers. Again, plane fitting was done, but now based on data of over 200 papers (Fig. 11, Eq. (31)). Small refinement was made

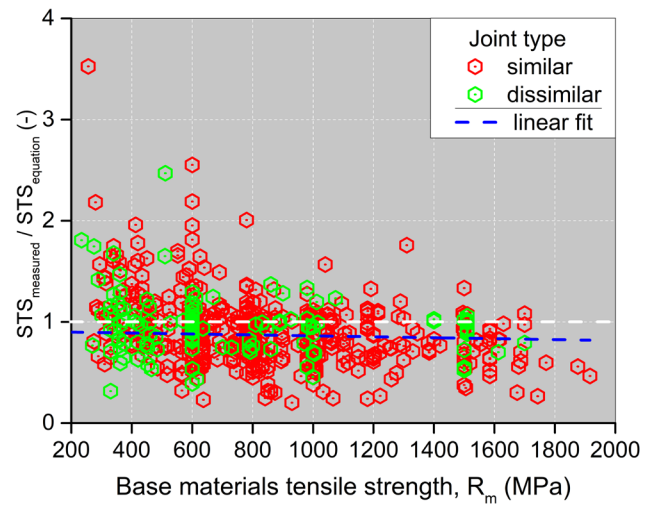


Fig. 10 Normalized STS values are shown according to Eq. (20).

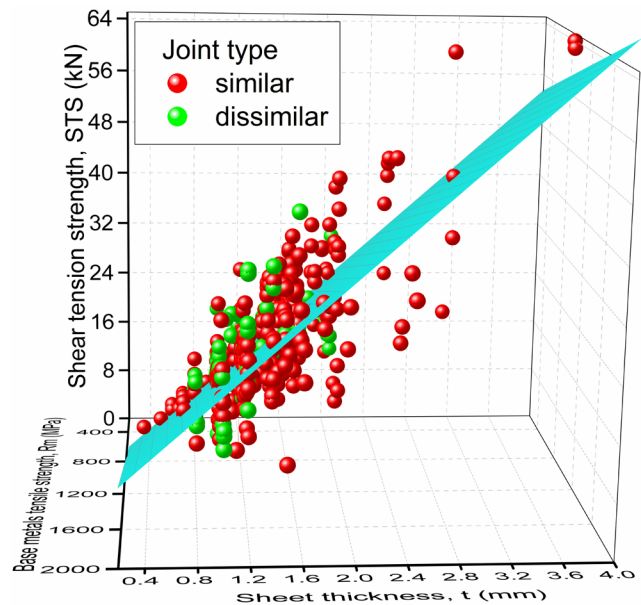


Fig. 11 Measured STS values are shown with the fitted plane according to Eq. (31), for similar and dissimilar RSWed joints. For the dissimilar joints, the weaker side is depicted.

compared to the previous fitting ($R^2 = 0.7$). It is still clearly seen, that, the main effect lies on the sheet thickness to be welded, and the base metals tensile strength also increases the STS values.

$$\text{STS}(\text{kN}) = -9.58 + 15.32 \cdot t + 0.0087 \cdot R_m \quad (31)$$

Normalized STS values for Eq. (31) can be seen in Fig. 12. The scatter is small, normalized STS values are between ~ 0.5 – 2.0 and the values scatter symmetrically around 1. Therefore, with a safety factor >2 this correlation can be used in the whole R_m range to predict the STS values in the design stage of the given RSWed component.

3.2 Evaluation of the CTS correlations

From the listed equations for the CTS values (Eqs. (21)–(30)) some could already be used in the planning stage for normal loaded RSWed joints. Of course, interfacial fracture is to avoid here too. If, the concrete material is not yet known for the part to be welded only the required tensile strength and thickness, Eqs. (26), (28) and Eq. (30) can be applied, therefore the literature data for those correlations was tested. CTS data for optimized joints from ~ 100 papers were analyzed. The CTS values for the optimized joints is plotted in Fig. 13 [12, 21, 23, 25, 33, 38, 39, 42, 43, 49, 60, 66, 67, 71, 80, 83, 84, 86, 100, 107–109, 134, 136, 143, 146, 150, 153, 158, 166, 167, 170–175, 179, 182–186, 188–190, 197, 200, 203, 206, 209–212, 214–220, 228, 232, 234, 235, 238, 249, 273, 275–304]. The dissimilar joints were represented as weaker side of the joint according to the requirement (Eq. (30)) of the AWS D8.1M:2013 standard [28].

The measured CTS values vs. the sheet thickness are plotted on Fig. 14.

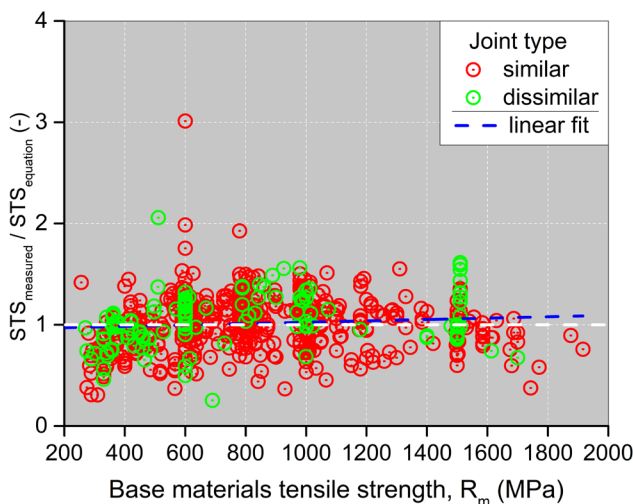


Fig. 12 Normalized STS values are shown according to Eq. (31), for similar and dissimilar RSWed joints. For the dissimilar joints, the weaker side is depicted.

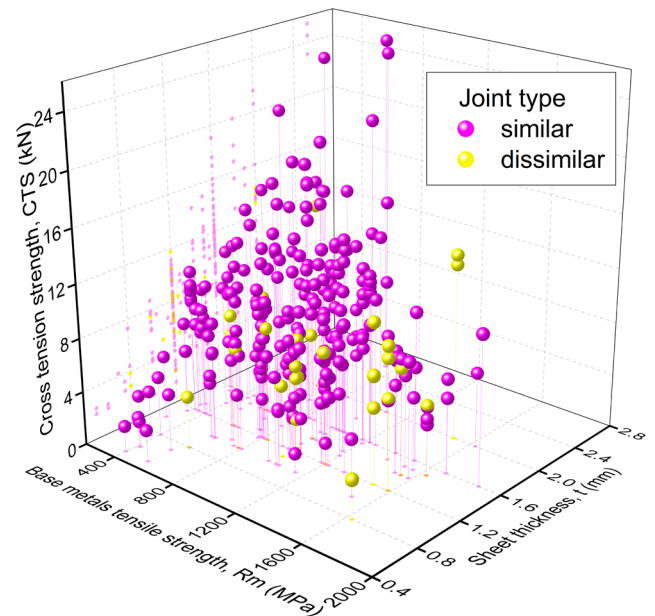


Fig. 13 Graphical representation of the literature data of the measured CTS values is shown in similar [12, 21, 23, 25, 33, 38, 39, 42, 43, 49, 60, 66, 67, 71, 80, 83, 84, 86, 100, 107–109, 134, 136, 143, 146, 150, 153, 158, 166, 167, 170–175, 179, 182–186, 188–190, 197, 200, 203, 206, 209–212, 214–220, 228, 232, 234, 235, 238, 249, 273, 275–304] and dissimilar [38, 43, 67, 107, 118, 134, 170, 214, 249, 250, 266, 282, 304, 305] RSWed joints.

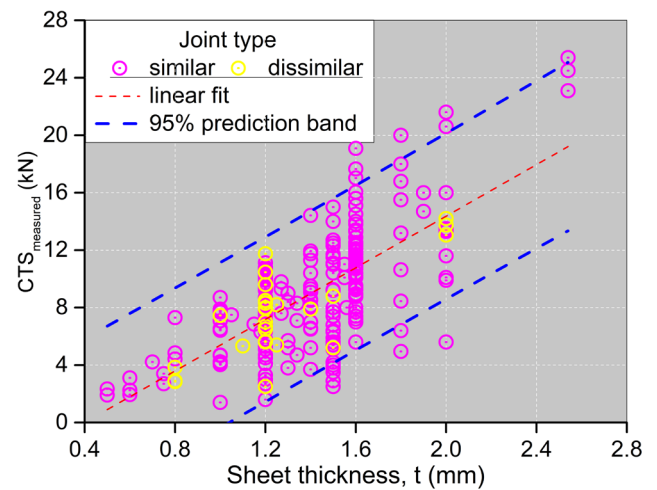


Fig. 14 The measured CTS values are shown for similar and dissimilar RSWed joints. For the dissimilar joints, the weaker side is depicted according to Eq. (30).

According to this diagram, the CTS values increase significantly with the sheet thickness, but the scatter is really high, e.g., for a steel sheet thickness of 1.6 mm the measured CTS values were between 6–18 kN. After linear fitting the CTS values for 1.6 mm thick sheets are predicted to be in the very wide range of 5–16 kN (95% prediction band). Therefore, the applicability of such equations where the sheet thickness is the only parameter for predicting the CTS values beforehand seems to be very limited.

In Fig. 15 the Eq. (30) (AWS D8.1M:2013 standard [28]) is investigated. As it can be seen, it fulfills its purpose by completely describing the minimal acceptable CTS values, because utmost normalized CTS values are above 1. (The same can be observed also in Fig. 16). The normalized values are basically in the whole investigated R_m range between 1–6 (eventually even 9) and a decreasing trend with higher R_m values can be observed. Therefore, Eq. (30) is not recommended for calculating the actual CTS value in the design stage.

As it was mentioned earlier, the nugget diameter d for good quality joints should be in the range of $3.5 - 5 \cdot \sqrt{t}$,

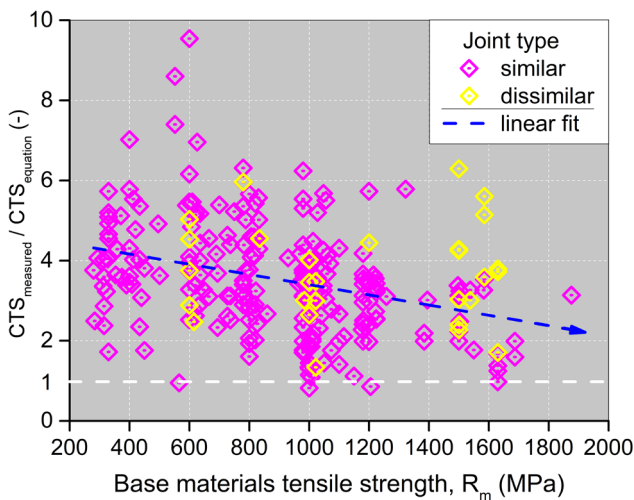


Fig. 15 Normalized CTS values are shown according to the requirement (Eq. (30)) of the AWS D8.1M:2013 standard [28] for similar and dissimilar RSWed joints. For the dissimilar joints, the weaker side is depicted.

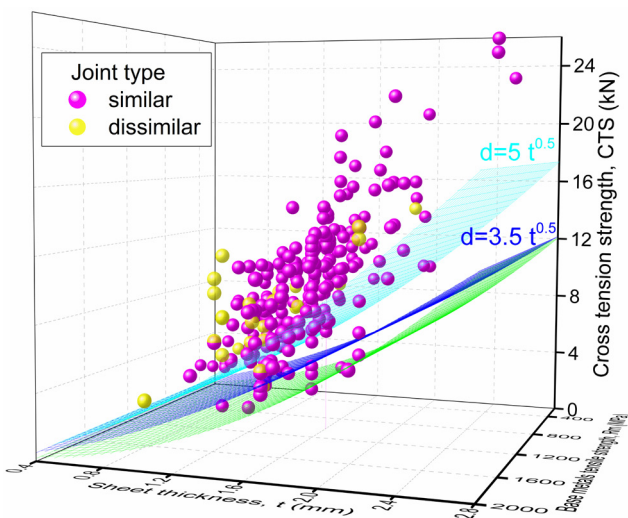


Fig. 16 Graphical representation of the literature data of the measured CTS values is shown in similar and dissimilar RSWed joints, planes are shown according to Eq. (26) (for different weld nugget sizes) in blue and according to Eq. (30) in green. The weaker side is depicted according to Eq. (30) for the dissimilar joints.

therefore Eq. (26) was investigated in this range. As it can be seen in Fig. 16, calculating with the nugget size $d = 3.5 \cdot \sqrt{t}$, Eq. (26) could be used as a boundary for the minimal acceptable CTS values similar to Eq. (30), but here a few more CTS values fall under the acceptance criteria. Increasing the assumed nugget size also increases the number of CTS values that fall under the acceptance criteria.

In the normalized CTS value plot for Eq. (26) for $d = 5 \cdot \sqrt{t}$ (Fig. 17) a slight decreasing trend for the normalized CTS values with higher base materials strength can be observed ($\sim 1.8 \pm 0.8$ at $R_m = 300$ MPa decreased to ~ 1.2 at $R_m = 1800$ MPa). Still, the values scatter in a smaller range (between 0.5–3) than for Eq. (30) therefore with a safety factor >2 Eq. (26) could be used for predicting the CTS of the joint, for design purposes.

Equation (28) is beneficial, because it takes not only the sheet thickness and nugget size, but also the base materials tensile strength into account. Sakuma and Oikawa [23] and Sakuma et al. [24] determined for their investigation's coefficient $J = 1.2-2.7$. For the global approach in the whole tensile strength range the normalized CTS values are plotted for $d = 3.5 \cdot \sqrt{t}$ and $d = 5 \cdot \sqrt{t}$ in Fig. 18. As it is obvious the normalized CTS values are constantly decreasing, and at some R_m (depending on the nugget size and factor J) it falls below 1. However, this correlation works well for the selected steel group in [23, 24], it does not give a global approach to predict CTS values, for design purposes in the whole tensile strength range.

A plane fitting on all the literature data of similar joints was made (Fig. 19) with Origin® software to cover the whole steel sheet range.

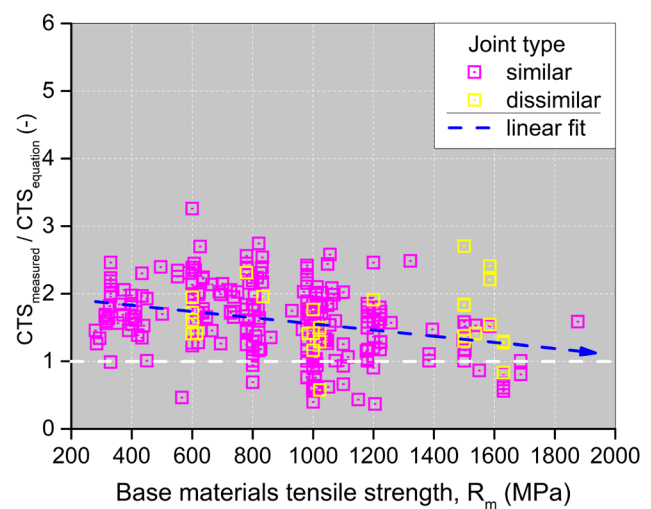


Fig. 17 Normalized CTS values are shown for Eq. (26) for similar and dissimilar RSWed joints, for the assumed nugget size $d = 5 \cdot \sqrt{t}$. For the dissimilar joints, the weaker side is depicted.

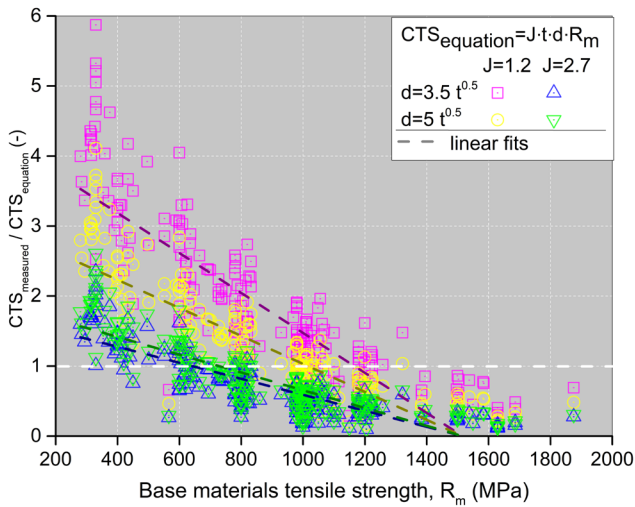


Fig. 18 Normalized CTS values are shown according to Eq. (28) (for $J=1.2$ and 2.7 the nugget sizes $d = 3.5 \cdot \sqrt{t}$ and $5 \cdot \sqrt{t}$) for similar RSWed joints.

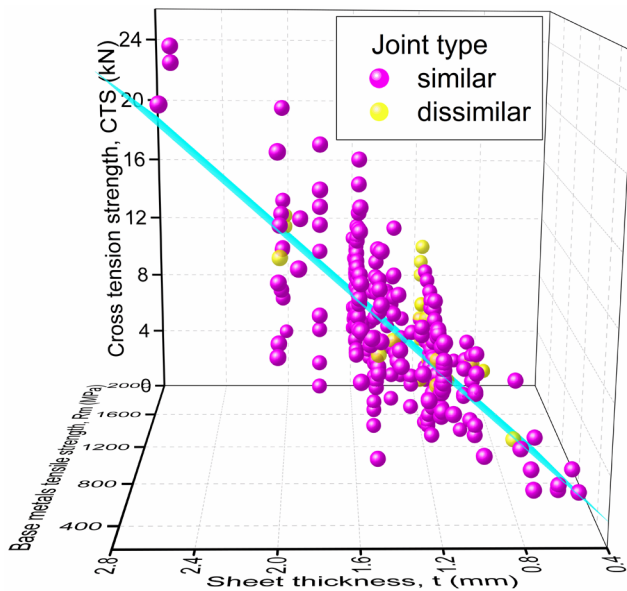


Fig. 19 Measured CTS values are shown with the fitted plane according to Eq. (32) for similar and dissimilar RSWed joints, for the dissimilar joints, the weaker side is depicted.

The fitted plane equation is Eq. (32).

$$STS(kN) = -1.74 + 9.76 \cdot t - 0.0034 \cdot R_m \quad (32)$$

According to Eq. (32) in the investigated range it seems; that the main effect on the CTS has the sheet thickness which increases its value and the base materials tensile strength slightly but decreases the achievable CTS.

The normalized CTS values for Eq. (32) can be seen in Fig. 20. For similar joints the normalized values scatter around 1 and they are between 0.5–2. In the case of the dissimilar joints if there is a large difference in the sheet

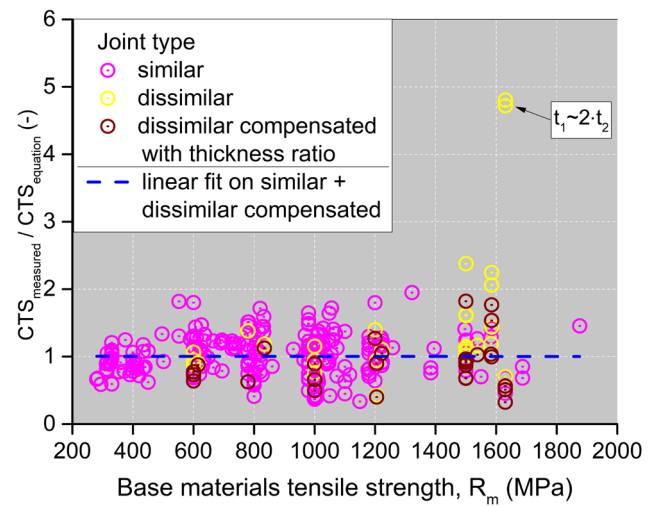


Fig. 20 Normalized CTS values are shown according to Eq. (32) for similar and dissimilar, and according to Eq. (33) for dissimilar (compensated) RSWed joints. For the dissimilar joints, the weaker side is depicted.

thickness of the two sides of the joint there were some high values ~ 5 . Therefore, in the case of the dissimilar joints the CTS values were compensated proportional with the sheet thickness ratios according to Eq. (33).

$$STS(kN) = (-1.74 + 9.76 \cdot t_1 - 0.0034 \cdot R_{m1}) \cdot t_1 / (t_1 + t_2) + (-1.74 + 9.76 \cdot t_2 - 0.0034 \cdot R_{m2}) \cdot t_2 / (t_1 + t_2) \quad (33)$$

After this compensation, normalized CTS values for the dissimilar joints are in the region of 0.4–2 too. According to these results, for similar joints Eq. (32) and for dissimilar joints Eq. (33) can be used in the planning stage of RSWed parts in the whole tensile strength range for thin sheets. For application the usage of a safety factor $2 >$ is needed.

4 Conclusions

In this study significant amount of literature data on resistance spot welding was analyzed and evaluated according to different kinds of shear tension strength and cross tension strength formulas. It was determined whether they are applicable to predict the strength of the RSWed joints in the planning stage of the manufacturing if only the sheet thickness and tensile strength of the base materials is known.

The literature data analysis using the different STS correlations showed:

- The AWS D8.1M:2013 standard's [28] equation (Eq. (17)) gives a good boundary for minimal achievable STS values in the whole tensile strength range, but to estimate the STS beforehand is not really applicable.
- Sawhill and Baker's [10] equation (Eq. (2)) with $A = 2.2$ and a presumed nugget size $d = 3.5 \cdot \sqrt{t}$ gives also a good boundary for minimal acceptable

STS values in the whole tensile strength range, but to estimate the STS beforehand is not really applicable either.

- Xu et al.'s [31, 32] equation (Eq. (20)), seems to be applicable to estimate the STS in the whole tensile strength range (with a safety factor ~ 3 needed).
- A new formula was proposed (Eq. (31)), which is even more applicable to estimate the STS depending on the steels sheet thickness (0.3–3.8 mm range) and their tensile strength (300–1900 MPa range), (with a safety factor ~ 2 needed).

The literature data analysis using the different CTS correlations showed:

- The AWS D8.1M:2013 standard's [28] equation (Eq. (30)) gives a good boundary for minimal achievable CTS values in the whole tensile strength range, but to estimate the CTS beforehand is not really applicable.
- Oikawa et al.'s [12, 13] equation (Eq. (26)) with a presumed nugget size $d = 3.5 \cdot \sqrt{t}$ gives also a good

boundary for minimal acceptable CTS values in the whole tensile strength range and also seems to be applicable to estimate the CTS (with a safety factor > 2 needed).

- A new formula was proposed to predict the cross tension strength for similar (Eq. (32)) and dissimilar (Eq. (33)) joints as well, depending on the steels sheet thickness (0.5–2.6 mm range) and their tensile strength (300–1900 MPa range), respectively (with a safety factor > 2 needed).

Acknowledgements

Project no. TKP-6-6/PALY-2021 has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the TKP2021-NVA funding scheme.

Parts of this paper has been supported by the National Research, Development and Innovation Office – NKFIH, OTKA PD 138729.

References

- [1] O'Brien, A. (ed.) "Welding Handbook Volume 3 - Welding Processes, Part 2", AWS, 2007. ISBN 978-0-87171-053-6
- [2] Zhang, Y., Lai, X., Zhu, P., Wang, W. "Lightweight design of automobile component using high strength steel based on dent resistance", *Materials & Design*, 27(1), pp. 64–68, 2006.
<https://doi.org/10.1016/j.matdes.2004.09.010>
- [3] Liu, Q., Zhou, Q., Venezuela, J., Zhang, M., Atrons, A. "Evaluation of the influence of hydrogen on some commercial DP, Q&P and TWIP advanced high-strength steels during automobile service", *Engineering Failure Analysis*, 94, pp. 249–273, 2018.
<https://doi.org/10.1016/j.engfailanal.2018.08.011>
- [4] Mei, L., Chen, G., Jin, X., Zhang, Y., Wu, Q. "Research on laser welding of high-strength galvanized automobile steel sheets", *Optics and Lasers in Engineering*, 47(11), pp. 1117–1124, 2009.
<https://doi.org/10.1016/j.optlaseng.2009.06.016>
- [5] Borhy, I., Kovács, L. "A Lightweight Design Approach for Welded Railway Vehicle Structures of Modern Passenger Coach", In: Jármai, K., Bolló, B. (eds.) *Vehicle and Automotive Engineering*, Springer, 2017, pp. 425–437. ISBN 978-3-319-51188-7
https://doi.org/10.1007/978-3-319-51189-4_37
- [6] Gyura, L., Gáspár, M., Balogh, A. "Investigation of Thermal Effects of Flame Straightening on High-Strength Steels", In: Jármai, K., Voith, K. (eds.) *Vehicle and Automotive Engineering 3*, Springer, 2021, pp. 526–538. ISBN 978-981-15-9528-8
https://doi.org/10.1007/978-981-15-9529-5_46
- [7] Sisodia, R. P. S., Gáspár, M., Sepsi, M., Mertinger, V. "Comparative evaluation of residual stresses in vacuum electron beam welded high strength steel S960QL and S960M butt joints", *Vacuum*, 184, 109931, 2021.
<https://doi.org/10.1016/j.vacuum.2020.109931>
- [8] Lukács, J., Mobark, H. F. H., Dobosy, Á. "High Cycle Fatigue Resistance of 700 MPa and 960 MPa Strength Categories High Strength Steels and Their Gas Metal Arc Welded Joints", In: Jármai, K., Voith, K. (eds.) *Vehicle and Automotive Engineering 3*, Springer, 2021, pp. 539–555. ISBN 978-981-15-9528-8
https://doi.org/10.1007/978-981-15-9529-5_47
- [9] Heuschkel J. "The Expression of Spot-Weld properties", *Welding Journal*, 31(10), pp. 931–943, 1952.
- [10] Sawhill, J. M., Baker, J. C. "Spot Weldability of High-Strength Sheet Steels", *Welding Journal*, 59(1), pp. 19-s–30-s, 1980.
- [11] Defourny, J., D'Haeyer, R., Bragard, A., Dawance, J., Mertens, A., Renard, L. "Spot welding of high strength steel sheets for deep drawing", *International Institute of Welding*, Genova, Italy, III-646-80, 2017.
- [12] Oikawa, H., Murayama, G., Sakiyama, T., Takahashi, Y., Ishikawa, T. "Resistance Spot Weldability of High Strength Steel (HSS) Sheets for Automobiles", *Nippon Steel Technical Report*, 95, pp. 39–45, 2007.
- [13] Oikawa, H., Murayama, G., Hiwatashi, S., Matsuyama, K. "Resistance Spot Weldability of High Strength Steel Sheets for Automobiles and the Quality Assurance of Joints", *Welding in the World*, 51(3–4), pp. 7–18, 2007.
<https://doi.org/10.1007/bf03266555>
- [14] Radakovic, D. J., Tumuluru, M. "Predicting Resistance Spot Weld Failure Modes in Shear Tension Tests of Advanced High-Strength Automotive Steels", *Welding Journal*, 87(4), pp. 96-s–105-s, 2008.
- [15] Pouranvari, M. "Understanding the factors controlling the interfacial failure strength of advanced high-strength steel resistance spot welds: hardness vs. fracture toughness", *Science and Technology of Welding and Joining*, 23(6), pp. 520–526, 2018.
<https://doi.org/10.1080/13621718.2017.1421303>

- [16] Cho, H., Nam, S., Kang, M., Kang, M., Kim, Y.-M. "Predicting Failure Modes of Resistance Spot Welds from the Chemical Composition of Materials", *Journal for Welding and Joining*, 38(5), pp. 450–459, 2020.
<https://doi.org/10.5781/JWJ.2020.38.5.4>
- [17] Tamizi, M., Pouranvari, M., Movahedi, M. "Welding metallurgy of martensitic advanced high strength steels during resistance spot welding", *Science and Technology of Welding and Joining*, 22(4), pp. 327–335, 2017.
<https://doi.org/10.1080/13621718.2016.1240979>
- [18] den Uijl, N. J., Nishibata, H., Smith, S., Okada, T., van der Veldt, T., Uchihara, M., Fukui, K. "Prediction of Post Weld Hardness of Advanced High Strength Steels for Automotive Application using a Dedicated Carbon Equivalent Number", *Welding in the World*, 52(11–12), pp. 18–29, 2008.
<https://doi.org/10.1007/BF03266679>
- [19] Vignier, S., Biro, E., Hervé, M. "Predicting the hardness profile across resistance spot welds in martensitic steels", *Welding in the World*, 58(3), pp. 297–305, 2014.
<https://doi.org/10.1007/s40194-014-0116-0>
- [20] Otani, T., Sasabe, K., Shiga, C., Nagashima N. "スポットヒーティングによる超細粒高強度鋼板の溶接部特性" (Characteristics of Welds of High Strength Steel Sheets with Ultra-fine Grained Microstructure Welded by Resistance Spot Heating Method), *Quarterly Journal of the Japan Welding Society*, 20(1), pp. 114–119, 2002. (in Japanese)
<https://doi.org/10.2207/qjwjs.20.114>
- [21] Ghassemi-Armaki, H., Bhat, S., Kelley, S., Sadagopan, S. "Quasi-Static Spot Weld Strength of Advanced High-Strength Sheet Steels", *Welding Journal*, 96(3), pp. 104-s–112-s, 2017.
- [22] Kuo, M., Chiang, J. "Weldability Study of Resistance Spot Welds and Minimum Weld Button Size Methodology Development for DP Steel", SAE International, Warrendale, PA, USA, SAE Technical Paper 2004-01-0169, 2004. ISBN 0-7680-1319-4
<https://doi.org/10.4271/2004-01-0169>
- [23] Sakuma, Y., Oikawa, H. "Factors to Determine Static Strengths of Spot-weld for High Strength Steel Sheets and Developments of High-strength Steel Sheets with Strong and Stable Welding Characteristics", *Nippon Steel Technical Report*, 88, pp. 33–38, 2003.
- [24] Sakuma, Y., Hiwatashi, S., Oikawa, H. "Advisable Grades of High-Strength Steel Sheets and Welding Conditions for Spot-Weld Strength in Automotive Body Application", SAE International, Warrendale, PA, USA, SAE Technical Paper 2003-01-2774, 2003.
<https://doi.org/10.4271/2003-01-2774>
- [25] Tumuluru, M. "The effect of coatings on the resistance spot welding behavior of 780 MPa dual-phase steel", *Welding Journal*, 86(6), pp. 161-s–169-s, 2007.
- [26] ISO "ISO 14373:2015 Resistance welding - Procedure for spot welding of uncoated and coated low carbon steels", International Organization for Standardization, Geneva, Switzerland, 2015.
- [27] BS "BS 1140:1993 Specification for resistance spot welding of uncoated and coated low carbon steel", British Standards Institution, London, UK, 1993.
- [28] AWS "AWS D8.1M:2013 Specification for automotive weld quality - resistance spot welding of steel", American Welding Society, Miami, FL, USA, 2013.
- [29] Varbai, B., Sommer, C., Szabó, M., Tóth, T., Májlinger, K. "Shear tension strength of resistant spot welded ultra high strength steels", *Thin-Walled Structures*, 142, pp. 64–73, 2019.
<https://doi.org/10.1016/j.tws.2019.04.051>
- [30] Májlinger, K., Katula, L. T., Varbai, B. "Prediction of the Shear Tension Strength of Resistance Spot Welded Thin Steel Sheets from High- to Ultrahigh Strength Range", *Periodica Polytechnica Mechanical Engineering*, 66(1), pp. 67–82, 2022.
<https://doi.org/10.3311/PPme.18934>
- [31] Xu, Z., Xiao, A., Jiang, S., Mao, L., Tian, H., Yi, B., Ling, H. "Effect of plate thickness on mechanical properties and failure behaviors of resistance spot welded advanced high strength steels", *Journal of Manufacturing Processes*, 95, pp. 392–404, 2023.
<https://doi.org/10.1016/j.jmapro.2023.04.008>
- [32] Xu, Z., Tian, C., Mao, L., Tian, H., Yi, B., Ling, H. "A mechanical properties and failure mechanism study for resistance spot welded AHSSs under coach-peel and lap-shear loads", *Engineering Fracture Mechanics*, 290, 109474, 2023.
<https://doi.org/10.1016/j.engfracmech.2023.109474>
- [33] Rajarajan, C., Sivaraj, P., Sonar, T., Raja, S., Mathiazhagan, N. "Resistance spot welding of advanced high strength steel for fabrication of thin-walled automotive structural frames", *Forces in Mechanics*, 7, 100084, 2022.
<https://doi.org/10.1016/j.finmec.2022.100084>
- [34] Ungureanu, V., Both, I., Burca, M., Radu, B., Neagu, C., Dubina, D. "Experimental and numerical investigations on built-up cold-formed steel beams using resistance spot welding", *Thin-Walled Structures*, 161, 107456, 2021.
<https://doi.org/10.1016/j.tws.2021.107456>
- [35] Ding, K., Wang, Y., Lei, M., Wei, T., Wu, G., Zhang, Y., Pan, H., Zhao, B., Gao, Y. "Numerical and experimental investigations on the enhancement of the tensile shear strength for resistance spot welded TWIP steel", *Journal of Manufacturing Processes*, 76, pp. 365–378, 2022.
<https://doi.org/10.1016/j.jmapro.2022.02.031>
- [36] Kizaki, T., Mikami, Y., Kawabe, N., Matsuda, H., Ikeda, R., Mochizuki, M. "Numerical Simulation of Hydrogen Diffusion and Accumulation Behavior under Residual Stress Distribution in Resistance Spot Welds", *Quarterly Journal of the Japan Welding Society*, 35(2), pp. 108s–111s, 2017.
<https://doi.org/10.2207/qjwjs.35.108s>
- [37] Choi, D.-Y., Mochizuki, M., Toyoda, M. "Numerical Simulation of Resistance Spot Welding Process for Automotive High Strength Steel", *Preprints of the National Meeting of JWS*, 2007f, 94, 2007.
<https://doi.org/10.14920/jwstaikai.2007f.0.94.0>
- [38] Dorribo, D., Greve, L., Díez, P., Arias, I., Larráyoiz-Izcara, X. "Numerical estimation of the bearing capacity of resistance spot welds in martensitic boron steels using a *J*-integral fracture criterion", *Theoretical and Applied Fracture Mechanics*, 96, pp. 497–508, 2018.
<https://doi.org/10.1016/j.tafmec.2018.06.006>
- [39] Prém, L., Bézi, Z., Balogh, A. "Development of Complex Spot Welding Technologies for Automotive DP Steels with FEM Support", In: Jármay, K., Bolló, B. (eds.) *Vehicle and Automotive Engineering*, Springer, 2017, pp. 407–423. ISBN 978-3-319-51188-7
https://doi.org/10.1007/978-3-319-51189-4_36

- [40] Vignesh, K., Perumal, A. E., Velmurugan, P. "Resistance spot welding of AISI-316L SS and 2205 DSS for predicting parametric influences on weld strength – Experimental and FEM approach", *Archives of Civil and Mechanical Engineering*, 19(4), pp. 1029–1042, 2019.
<https://doi.org/10.1016/j.acme.2019.05.002>
- [41] Tonbe, Y., Nagano, T., Okada, H. "ジグ試験片間の滑りを許容した十字継手引張試験(CTS)のFEM解析" (FEM analysis of cross tension test (CTS) that allows slips between jig and test piece, *Quarterly Journal of the Japan Welding Society*, 41(1), pp. 18–25, 2023. (in Japanese)
<https://doi.org/10.2207/qjwjs.41.18>
- [42] Kosnan, M. S. E., Ahmad, Z., Borhana, A. A., Tamin, M. N. "Finite Element Simulation of Ductile Failure Process of Spot-Welded Joint under Tension Loading", *Applied Mechanics and Materials*, 660, pp. 623–627, 2014.
<https://doi.org/10.4028/www.scientific.net/AMM.660.623>
- [43] Dancette, S., Fabregue, D., Estevez, R., Massardier, V., Dupuy, T., Bouzekri, M. "A finite element model for the prediction of Advanced High Strength Steel spot welds fracture", *Engineering Fracture Mechanics*, 87, pp. 48–61, 2012.
<https://doi.org/10.1016/j.engfracmech.2012.03.004>
- [44] Chen, G., Sheng, B., Luo, R., Jia, P. "A parallel strategy for predicting the quality of welded joints in automotive bodies based on machine learning", *Journal of Manufacturing Systems*, 62, pp. 636–649, 2022.
<https://doi.org/10.1016/j.jmsy.2022.01.011>
- [45] Hwang, I., Yun, H., Yoon, J., Kang, M., Kim, D., Kim, Y.-M. "Prediction of Resistance Spot Weld Quality of 780 MPa Grade Steel Using Adaptive Resonance Theory Artificial Neural Networks", *Metals*, 8(6), 453, 2018.
<https://doi.org/10.3390/met8060453>
- [46] Hamed, M., Shariatpanahi, M., Mansourzadeh, A. "Optimizing spot welding parameters in a sheet metal assembly by neural networks and genetic algorithm", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 221(7), pp. 1175–1184, 2007.
<https://doi.org/10.1243/09544054JEM476>
- [47] Wang, B., Qiu, F., Chen, L., Zhou, Q., Dong, B., Yang, H., Yang, J., Feng, Z., Tyrer, N., Barber, G. C., Hu, M. "Microstructure and shearing strength of stainless steel/low carbon steel joints produced by resistance spot welding", *Journal of Materials Research and Technology*, 20, pp. 2668–2679, 2022.
<https://doi.org/10.1016/j.jmrt.2022.08.041>
- [48] Gang, W., Tian, C., Dongdong, Z. "Study on prediction of tensile-shear strength of weld spot based on an improved neural network algorithm", *Welding in the World*, 67(3), pp. 741–752, 2023.
<https://doi.org/10.1007/s40194-022-01406-1>
- [49] Chung, K., Noh, W., Yang, X., Han, H. N., Lee, M.-G. "Practical failure analysis of resistance spot welded advanced high-strength steel sheets", *International Journal of Plasticity*, 94, pp. 122–147, 2017.
<https://doi.org/10.1016/j.ijplas.2016.10.010>
- [50] Long, H., Hu, Y., Jin, X., Shao, J., Zhu, H. "Effect of holding time on microstructure and mechanical properties of resistance spot welds between low carbon steel and advanced high strength steel", *Computational Materials Science*, 117, pp. 556–563, 2016.
<https://doi.org/10.1016/j.commatsci.2016.01.011>
- [51] Ao, S., Shan, H., Cui, X., Luo, Z., Chao, Y. J., Ma, M. "Effect of specimen width on the failure behavior in resistance spot weld tensile shear testing", *Welding in the World*, 60(6), pp. 1095–1107, 2016.
<https://doi.org/10.1007/s40194-016-0384-y>
- [52] Zhao, D. W., Wang, Y. X., Zhang, L., Zhang, P. "Effects of electrode force on microstructure and mechanical behavior of the resistance spot welded DP600 joint", *Materials & Design*, 50, pp. 72–77, 2013.
<https://doi.org/10.1016/j.matdes.2013.02.016>
- [53] Zhao, Y. Y., Zhang, Y. S., Wang, P.-C. "Weld Formation Characteristics in Resistance Spot Welding of Ultra-Thin Steel", *Welding Journal*, 96(2), pp. 71-s–82-s, 2017.
- [54] Weber, G., Göklü, S. "Resistance Spot Welding of Uncoated and Zinc Coated Advanced High-Strength Steels (AHSS) — Weldability and Process Reliability-Influence of Welding Parameters", *Welding in the World*, 50(3–4), pp. 3–12, 2006.
<https://doi.org/10.1007/bf03263428>
- [55] Pal, T. K., Bhowmick, K. "Resistance Spot Welding Characteristics and High Cycle Fatigue Behavior of DP 780 Steel Sheet", *Journal of Materials Engineering and Performance*, 21(2), pp. 280–285, 2012.
<https://doi.org/10.1007/s11665-011-9850-2>
- [56] Ertek Emre, H., Kaçar, R. "Resistance Spot Weldability of Galvanize Coated and Uncoated TRIP Steels", *Metals*, 6(12), 299, 2016.
<https://doi.org/10.3390/met6120299>
- [57] Ghassemi-Armaki, H., Bhat, S., Kelley, S., Sadagopan, S. "Quasi Static Spot Weld Strength of Advanced High Strength Sheet Steels", *Welding Journal*, 96(3), pp. 104-s–112-s, 2017.
- [58] Sevim, I., Hayat, F., Kulekci, M. K. "Nucleus geometry and mechanical properties of resistance spot welded coated–uncoated DP automotive steels", *Bulletin of Materials Science*, 36(6), pp. 1049–1055, 2013.
<https://doi.org/10.1007/s12034-013-0559-8>
- [59] Wan, X., Wang, Y., Zhang, P. "Modelling the effect of welding current on resistance spot welding of DP600 steel", *Journal of Materials Processing Technology*, 214(11), pp. 2723–2729, 2014.
<https://doi.org/10.1016/j.jmatprotec.2014.06.009>
- [60] Bouzekri, M., Dancette, S., Dupuy, T., Lens, A., Nait Oulit, B., Massardier, V., Fabrègue, D., Klocker, H. "An Investigation of Failure Types in High-Strength Steel Resistance Spot Welds", *Welding in the World*, 54(3–4), pp. 3–14, 2010.
<https://doi.org/10.1007/bf03263485>
- [61] Liang, X., Yuan, X., Wang, H., Li, X., Li, C., Pan, X. "Microstructure, mechanical properties and failure mechanisms of resistance spot welding joints between ultra high strength steel 22MnB5 and galvanized steel HSLA350", *International Journal of Precision Engineering and Manufacturing*, 17(12), pp. 1659–1664, 2016.
<https://doi.org/10.1007/s12541-016-0192-8>
- [62] Liu, W., Wang, R., Han, J., Xu, X., Li, Q. "Microstructure and mechanical performance of resistance spot-welded cold-rolled high strength austenitic stainless steel", *Journal of Materials Processing Technology*, 210(14), pp. 1956–1961, 2010.
<https://doi.org/10.1016/j.jmatprotec.2010.07.008>
- [63] Daneshpour, S., Koçak, M., Riekehr, S., Gerritsen, C. H. J. "Mechanical Characterization and Fatigue Performance of Laser and Resistance Spot Welds", *Welding in the World*, 53(9–10), pp. R221–R228, 2009.
<https://doi.org/10.1007/bf03321133>

- [64] Brauser, S., Pepke, L.-A., Weber, G., Rethmeier, M. "Influence of Production-Related Gaps on Strength Properties and Deformation Behaviour of Spot Welded Trip Steel HCT690T", *Welding in the World*, 56(3–4), pp. 115–125, 2012.
<https://doi.org/10.1007/bf03321342>
- [65] Pouranvari, M., Marashi, S. P. H. "Failure mode transition in AHSS resistance spot welds. Part I. Controlling factors", *Materials Science and Engineering: A*, 528(29–30), pp. 8337–8343, 2011.
<https://doi.org/10.1016/j.msea.2011.08.017>
- [66] Rossillon, F., Galtier, A., Robert, J. L., Duchet, M., Lens, A., Oikawa, H. "Effect of Welding Cycle on the Fatigue Behaviour of Resistance Spot Welded Dual Phase Steels", *Welding in the World*, 52(11–12), pp. 30–41, 2008.
<https://doi.org/10.1007/bf03266680>
- [67] Tolf, E., Hedegård, J. "Influence of Reduced Cooling Time on the Properties of Resistance Spot Welds", *Welding in the World*, 52(3–4), pp. 43–53, 2008.
<https://doi.org/10.1007/bf03266631>
- [68] Den Uijl, N., Moolevliet, T., Mennes, A., Van Der Ellen, A. A., Smith, S., Van Der Veldt, T., Okada, T., Nishibata, H., Uchiyama, M., Fukui, K. "Performance of Resistance Spot-Welded Joints in Advanced High-Strength Steel in Static and Dynamic Tensile Tests", *Welding in the World*, 56(7–8), pp. 51–63, 2012.
<https://doi.org/10.1007/bf03321365>
- [69] den Uijl, N., Azakane, F., Kilic, S., Docter, V. "Performance of Tensile Tested Resistance Spot and Laser Welded Joints at Various Angles", *Welding in the World*, 56(11–12), pp. 143–152, 2012.
<https://doi.org/10.1007/bf03321404>
- [70] Yu, J., Shim, J., Rhee, S. "Characteristics of Resistance Spot Welding for 1 GPa Grade Twin Induced Plasticity Steel", *Materials Transactions*, 53(11), pp. 2011–2018, 2012.
<https://doi.org/10.2320/matertrans.M2012167>
- [71] Abadi, M. M. H., Pouranvari, M. "Failure-mode transition in resistance spot welded DP780 advanced high-strength steel: effect of loading conditions", *Materiali in Tehnologije/Materials and Technology*, 48(1), pp. 67–71, 2014.
- [72] Eva, S., Bohumil, C., Petr, H. "Dynamic Fracture Behavior of the Martensitic High Strength Steel after Spot Welding", *Materials Today: Proceedings*, 3(4), pp. 1156–1160, 2016.
<https://doi.org/10.1016/j.matpr.2016.03.014>
- [73] Khan, M. I., Kuntz, M. L., Biro, E., Zhou, Y. "Microstructure and Mechanical Properties of Resistance Spot Welded Advanced High Strength Steels", *Materials Transactions*, 49(7), pp. 1629–1637, 2008.
<https://doi.org/10.2320/matertrans.MRA2008031>
- [74] Wei, S. T., Lv, D., Liu, R. D., Lin, L., Xu, R. J., Guo, J. Y., Wang, K. Q. "Similar and dissimilar resistance spot welding of advanced high strength steels: welding and heat treatment procedures, structure and mechanical properties", *Science and Technology of Welding and Joining*, 19(5), pp. 427–435, 2014.
<https://doi.org/10.1179/1362171814y.00000000211>
- [75] John, B. "A Comparative Study of Joint Efficiency for Advanced High Strength Steel", [pdf] Auto/Steel Partnership, n.d.. Available at: <http://www.autosteel.org/~media/Files/Autosteel/Great%20Designs%20in%20Steel/GDIS%202009/11%20-%20A%20Comparative%20Study%20of%20Joint%20Efficiency%20for%20AHSS.pdf> [Accessed: 10 May 2017]
- [76] Kazdal Zeytin, H., Ertek Emre, H., Kaçar, R. "Properties of Resistance Spot-Welded TWIP Steels", *Metals*, 7(1), 14, 2017.
<https://doi.org/10.3390/met7010014>
- [77] Prém, L., Balogh, A., Bézi, Z. "A kísérletes technológiafejlesztés hatékonyságának javítása végelelemes modellezés alkalmazásával nagyszilárdságú DP acélok ponthegeztésekor" (Improvement in effectiveness of experimental technology development by finite element modelling for resistance spot welding of high strength DP steels), In: Palotás, B. (ed.) 28. Nemzetközi Hegesztési Konferencia, Dunaújváros, Hungary, 2016, pp. 85–111. ISBN 978-963-12-5101-2 (in Hungarian)
- [78] Prém, L., Balogh, A. "A szakaszos energiabevitelben rejlő lehetőségek kiaknázása nagyszilárdságú, ferrit-martensites duplex szövétű autóipari acélok ellenállás-ponthegeztésekor" (Exploiting the potential of intermittent energy input in resistance spot welding of high strength ferritic-martensitic duplex phase automotive steels), *Hegesztéstechnika*, 26(3), pp. 47–56, 2015. (in Hungarian)
- [79] Russo Spena, P., De Maddis, M., Lombardi, F., Rossini, M. "Investigation on Resistance Spot Welding of TWIP Steel Sheets", *steel research international*, 86(12), pp. 1480–1489, 2015.
<https://doi.org/10.1002/srin.201400336>
- [80] Tolf, E. "Challenges in Resistance Welding of Ultra High Strength Steels", *Licentiate Thesis*, KTH Royal Institute of Technology, 2015. ISBN 978-91-7595-577-3
- [81] Sperle, J.-O., Olsson, K. "High-strength automotive sheet steels for weight reductions and safety applications", In: *High-strength Steels for Automotive Symposium Proceedings*, Baltimore, MD, USA, 1994, pp. 65–77. ISBN 9780932897947
- [82] Marashi, P., Pouranvari, M., Sanaee, S. M. H., Abedi, A., Abotalebi, S. H., Goodarzi, M. "Relationship between failure behaviour and weld fusion zone attributes of austenitic stainless steel resistance spot welds", *Materials Science and Technology*, 24(12), pp. 1506–1512, 2008.
<https://doi.org/10.1179/174328408x262418>
- [83] Yi, H. L., Lee, K. Y., Lim, J. H., Bhadeshia, H. K. D. H. "Spot weldability of δ -TRIP steel containing 0.4 wt-%C", *Science and Technology of Welding and Joining*, 15(7), pp. 619–624, 2010.
<https://doi.org/10.1179/136217110x12813393169778>
- [84] Ertek Emre, H., Kaçar, R. "Effect of Button Geometry on TRIP800 Steel Resistance Spot Weldment", *International Journal of Innovative Research in Science, Engineering and Technology*, 5(12), pp. 164–171, 2016.
- [85] Pouranvari, M., Mousavizadeh, S. M. "Failure mode of M130 martensitic steel resistance-spot welds", *Materiali in Tehnologije/Materials and Technology*, 47(6), pp. 771–777, 2013.
- [86] Dancette, S., Massardier-Jourdan, V., Merlin, J., Fabrègue, D., Dupuy, T. "Investigations on the Mechanical Behavior of Advanced High Strength Steels Resistance Spot Welds in Cross Tension and Tensile Shear", *Advanced Materials Research*, 89–91, pp. 130–135, 2010.
<https://doi.org/10.4028/www.scientific.net/AMR.89-91.130>
- [87] Khan, M. I. "Spot Welding of Advanced High Strength Steels", *MSc Thesis*, University of Waterloo, 2007. ISBN 9780494343326

- [88] Marrya, M., Gayden, X. Q. "Development of Requirements for Resistance Spot Welding Dual-Phase (DP600) Steels Part 1 — The Causes of Interfacial Fracture", *Welding Journal*, 84(11), pp. 172-s–182-s, 2005.
- [89] Kiss, L., Májlinger, K., Varbai, B. "Nagyszilárdságú acéllemezek ellenállás-ponthegesztettkötéseinek optimalizálása" (Optimization of the resistance spot welded joints of high strength steel sheets), In: OGÉT 2017: XXV. Nemzetközi Gépészeti Konferencia, Kolozsvár, Romania, 2017, pp. 219–222. (in Hungarian)
- [90] Vajdics, D., Kovács-Coskun, T. "A TRIP acél ponthegesztésének hatása" (Resistance Spot Welding Effect in Case of TRIP Steel), *Műszaki Tudományos Közlemények*, 2, pp. 227–234, 2015. (in Hungarian)
<https://doi.org/10.33895/mtk-2015.02.26>
- [91] Hunt, J., Sang, Y. (J.), Jiang, C. (C.) "A/SP Joining Technology Committee Joint Efficiency and Repair Welding Phase II: Executive Summary", [pdf] Auto/Steel Partnership, Southfield, MI, USA, 2009. Available at: <https://www.a-sp.org/wp-content/uploads/2020/08/AHSS-Joining-Joint-Efficiency-Phase-II-Executive-Summary.pdf> [Accessed: 10 July 2023]
- [92] Kapil, A., Lee, T., Vivek, A., Bockbrader, J., Abke, T., Daehn, G. "Benchmarking strength and fatigue properties of spot impact welds", *Journal of Materials Processing Technology*, 255, pp. 219–233, 2018.
<https://doi.org/10.1016/j.jmatprotec.2017.12.012>
- [93] Martin, Ó., De Tiedra, P., San-Juan, M. "Combined effect of resistance spot welding and precipitation hardening on tensile shear load bearing capacity of A286 superalloy", *Materials Science and Engineering: A*, 688, pp. 309–314, 2017.
<https://doi.org/10.1016/j.msea.2017.02.015>
- [94] Pouranvari, M. "Fracture toughness of martensitic stainless steel resistance spot welds", *Materials Science and Engineering: A*, 680, pp. 97–107, 2017.
<https://doi.org/10.1016/j.msea.2016.10.088>
- [95] Papadimitriou, I., Efthymiadis, P., Kotadia, H. R., Sohn, I. R., Sridhar, S. "Joining TWIP to TWIP and TWIP to aluminium: A comparative study between joining processes, joint properties and mechanical performance", *Journal of Manufacturing Processes*, 30, pp. 195–207, 2017.
<https://doi.org/10.1016/j.jmapro.2017.09.012>
- [96] Rao, S. S., Chhibber, R., Arora, K. S., Shome, M. "Resistance spot welding of galvanized high strength interstitial free steel", *Journal of Materials Processing Technology*, 246, pp. 252–261, 2017.
<https://doi.org/10.1016/j.jmatprotec.2017.03.027>
- [97] Shirmohammadi, D., Movahedi, M., Pouranvari, M. "Resistance spot welding of martensitic stainless steel: Effect of initial base metal microstructure on weld microstructure and mechanical performance", *Materials Science and Engineering: A*, 703, pp. 154–161, 2017.
<https://doi.org/10.1016/j.msea.2017.07.067>
- [98] Pouranvari, M., Sobhani, S., Goodarzi, F. "Resistance spot welding of MS1200 martensitic advanced high strength steel: Microstructure-properties relationship", *Journal of Manufacturing Processes*, 31, pp. 867–874, 2018.
<https://doi.org/10.1016/j.jmapro.2018.01.009>
- [99] Brauser, S., Pepke, L. A., Weber, G., Rethmeier, M. "Deformation behaviour of spot-welded high strength steels for automotive applications", *Materials Science and Engineering: A*, 527(26), pp. 7099–7108, 2010.
<https://doi.org/10.1016/j.msea.2010.07.091>
- [100] Lin, H. J., Kim, W. J., Chang, H. S., Choi, D. Y. "Effect of profile force on toughness of resistance spot weld joints for ultra high strength steel", *Welding in the World*, 62(3), pp. 481–496, 2018.
<https://doi.org/10.1007/s40194-018-0571-0>
- [101] Mahmood, T. R., Doos, Q. M., Al-Mukhtar, A. M. "Failure Mechanisms and Modeling of Spot Welded Joints in Low Carbon Mild Sheets Steel and High Strength Low Alloy Steel", *Procedia Structural Integrity*, 9, pp. 71–85, 2018.
<https://doi.org/10.1016/j.prostr.2018.06.013>
- [102] Noh, W., Koh, Y., Chung, K., Song, J.-H., Lee, M.-G. "Influence of dynamic loading on failure behavior of spot welded automotive steel sheets", *International Journal of Mechanical Sciences*, 144, pp. 407–426, 2018.
<https://doi.org/10.1016/j.ijmecsci.2018.06.009>
- [103] Hsu, T.-I., Wu, L.-T., Tsai, M.-H. "Resistance and friction stir spot welding of dual-phase (DP 780)—a comparative study", *The International Journal of Advanced Manufacturing Technology*, 97(5–8), pp. 2293–2299, 2018.
<https://doi.org/10.1007/s00170-018-2056-0>
- [104] Xing, B., Xiao, Y., Qin, Q. H., Cui, H. "Quality assessment of resistance spot welding process based on dynamic resistance signal and random forest based", *The International Journal of Advanced Manufacturing Technology*, 94(1–4), pp. 327–339, 2018.
<https://doi.org/10.1007/s00170-017-0889-6>
- [105] Nadimi, N., Pouranvari, M., Ansari, R., Pouranvari, M. "Understanding fusion zone hardness in resistance spot welds for advanced high strength steels: Strengthening mechanisms and data-driven modeling", *Journal of Material Research and Technology*, 26, pp. 5549–5565, 2023.
<https://doi.org/10.1016/j.jmrt.2023.08.251>
- [106] Zhao, D., Wang, Y., Liang, D., Zhang, P. "Modeling and process analysis of resistance spot welded DP600 joints based on regression analysis", *Materials & Design*, 110, pp. 676–684, 2016.
<https://doi.org/10.1016/j.matdes.2016.08.038>
- [107] Paveebunvipak, K., Uthaisangsuk, V. "Microstructure based modeling of deformation and failure of spot-welded advanced high strength steels sheets", *Materials & Design*, 160, pp. 731–751, 2018.
<https://doi.org/10.1016/j.matdes.2018.09.052>
- [108] Liu, X. D., Xu, Y. B., Misra, R. D. K., Peng, F., Wang, Y., Du, Y. B. "Mechanical properties in double pulse resistance spot welding of Q&P 980 steel", *Journal of Materials Processing Technology*, 263, pp. 186–197, 2019.
<https://doi.org/10.1016/j.jmatprotec.2018.08.018>
- [109] Ashiri, R., Mostaan, H., Park, Y.-D. "A Phenomenological Study of Weld Discontinuities and Defects in Resistance Spot Welding of Advanced High Strength TRIP Steel", *Metallurgical and Materials Transactions A*, 49(12), pp. 6161–6172, 2018.
<https://doi.org/10.1007/s11661-018-4900-0>

- [110] Zhang, X., Yao, F., Ren, Z., Yu, H. "Effect of Welding Current on Weld Formation, Microstructure, and Mechanical Properties in Resistance Spot Welding of CR590T/340Y Galvanized Dual Phase Steel", *Materials*, 11(11), 2310, 2018.
<https://doi.org/10.3390/ma11112310>
- [111] Zhang, J. P., Feng, Y., Song, L. F., Wang, G. Y., Jin, Q. S. "Research on Resistance Spot Welding Property of Hot-Stamping Quenched Steel Sheets", *Advanced Materials Research*, 1063, pp. 120–125, 2015.
<https://doi.org/10.4028/www.scientific.net/AMR.1063.120>
- [112] Kimoto, N., Aito, T., Kawachi, T., Hiwatashi, S. "Strengthening mechanism of weldbonded high strength steel joints", *Procedia Manufacturing*, 15, pp. 1399–1406, 2018.
<https://doi.org/10.1016/j.promfg.2018.07.342>
- [113] Kong, J. P., Han, T. K., Chin, K. G., Park, B. G., Kang, C. Y. "Effect of boron content and welding current on the mechanical properties of electrical resistance spot welds in complex-phase steels", *Materials & Design*, 54, pp. 598–609, 2014.
<https://doi.org/10.1016/j.matdes.2013.08.098>
- [114] Pouranvari, M., Asgari, H. R., Mosavizadch, S. M., Marashi, P. H., Goodarzi, M. "Effect of weld nugget size on overload failure mode of resistance spot welds", *Science and Technology of Welding and Joining*, 12(3), pp. 217–225, 2007.
<https://doi.org/10.1179/174329307x164409>
- [115] Pouranvari, M., Marashi, S. P. H. "Key factors influencing mechanical performance of dual phase steel resistance spot welds", *Science and Technology of Welding and Joining*, 15(2), pp. 149–155, 2010.
<https://doi.org/10.1179/136217109x12590746472535>
- [116] Hernandez, B. V. H., Kuntz, M. L., Khan, M. I., Zhou, Y. "Influence of microstructure and weld size on the mechanical behaviour of dissimilar AHSS resistance spot welds", *Science and Technology of Welding and Joining*, 13(8), pp. 769–776, 2008.
<https://doi.org/10.1179/136217108x325470>
- [117] Park, S.-S., Choi, Y.-M., Nam, D.-G., Kim, Y.-S., Yu, J.-H., Park, Y.-D. "인장전단시험을 이용한 TRIP1180강의 계면파단특성 평가" (Evaluation of Resistance Spot Weld Interfacial Fractures in Tensile-Shear Tests of TRIP 1180 Steels), *Journal of Welding and Joining*, 26(6), pp. 81–91, 2008. (in Korean)
<https://doi.org/10.5781/KWJS.2008.26.6.081>
- [118] Baltazar Hernandez, V. H. "Effects of Martensite Tempering on HAZ-Softening and Tensile Properties of Resistance Spot Welded Dual-Phase Steels", PhD Thesis, University of Waterloo, 2010.
- [119] Zhao, Y., Zhang, Y., Lai, X. "Analysis of Fracture Modes of Resistance Spot Welded Hot-Stamped Boron Steel", *Metals*, 8(10), 764, 2018.
<https://doi.org/10.3390/met8100764>
- [120] Pouranvari, M., Marashi, S. P. H., Mousavizadeh, S. M. "Failure mode transition and mechanical properties of similar and dissimilar resistance spot welds of DP600 and low carbon steels", *Science and Technology of Welding and Joining*, 15(7), pp. 625–631, 2010.
<https://doi.org/10.1179/136217110x12813393169534>
- [121] Pouranvari, M. "Failure mode transition in similar and dissimilar resistance spot welds of HSLA and low carbon steels", *Canadian Metallurgical Quarterly*, 51(1), pp. 67–74, 2012.
<https://doi.org/10.1179/1879139511y.00000000020>
- [122] Noh, W. R., Koh, Y. W., Hong, J. H., Yang, X., Chung, K. S. "Failure Performance Analysis of Resistance Spot Welded Advanced High Strength Steel Sheets", *Key Engineering Materials*, 651–653, pp. 895–900, 2015.
<https://doi.org/10.4028/www.scientific.net/KEM.651-653.895>
- [123] Liu, R., Rao, M., Liu, S., Zhang, J., Luo, G. "Resistance Spot Welding Process and Properties of Hot Dip Galvanized DP590 High Strength Steel", In: Han, Y. (ed.) *Advances in Materials Processing*, Springer, 2018, pp. 743–749. ISBN 978-981-13-0106-3
https://doi.org/10.1007/978-981-13-0107-0_71
- [124] Russo Spena, P., De Maddis, M., Lombardi, F., D'Aiuto, F. "Resistance Spot Welding of Advanced High Strength TWIP Steels", *Applied Mechanics and Materials*, 423–426, pp. 876–880, 2013.
<https://doi.org/10.4028/www.scientific.net/AMM.423-426.876>
- [125] Borhy, I., Tóth, T. K. "Termomechanikus hengerelt nagyszilárdságú acélok ellenállás ponthegesztési technológiájának optimalizálása" (Optimisation of resistance spot welding technology for thermomechanically rolled high strength steels), *Hegesztéstechnika*, 29(4), pp. 47–51, 2018. (in Hungarian)
- [126] He, L., DiGiovanni, C., Han, X., Mehling, C., Wintjes, E., Biro, E., Zhou, N. Y. "Suppression of liquid metal embrittlement in resistance spot welding of TRIP steel", *Science and Technology of Welding and Joining*, 24(6), pp. 579–586, 2019.
<https://doi.org/10.1080/13621718.2019.1573011>
- [127] Kishore, K., Kumar, P., Mukhopadhyay, G. "Resistance spot weldability of galvanized and bare DP600 steel", *Journal of Materials Processing Technology*, 271, pp. 237–248, 2019.
<https://doi.org/10.1016/j.jmatprotec.2019.04.005>
- [128] Wintjes, E., DiGiovanni, C., He, L., Biro, E., Zhou, N. Y. "Quantifying the link between crack distribution and resistance spot weld strength reduction in liquid metal embrittlement susceptible steels", *Welding in the World*, 63(3), pp. 807–814, 2019.
<https://doi.org/10.1007/s40194-019-00712-5>
- [129] Ordoñez, J. H., Ambriz, R. R., García, C., Plascencia, G., Jaramillo, D. "Overloading effect on the fatigue strength in resistance spot welding joints of a DP980 steel", *International Journal of Fatigue*, 121, pp. 163–171, 2019.
<https://doi.org/10.1016/j.ijfatigue.2018.12.026>
- [130] Zhao, D., Wang, Y., Zhang, P., Liang, D. "Modeling and Experimental Research on Resistance Spot Welded Joints for Dual-Phase Steel", *Materials*, 12(7), 1108, 2019.
<https://doi.org/10.3390/ma12071108>
- [131] Jia, Q., Liu, L., Guo, W., Peng, Y., Zou, G., Tian, Z., Zhou, N. Y. "Microstructure and Tensile-Shear Properties of Resistance Spot-Welded Medium Mn Steel", *Metals*, 8(1), 48, 2018.
<https://doi.org/10.3390/met8010048>
- [132] Qiao, Z., Li, H., Li, L., Ran, X., Feng, L. "Microstructure and Properties of Spot Welded Joints of Hot-Stamped Ultra-High Strength Steel Used for Automotive Body Structures", *Metals*, 9(3), 285, 2019.
<https://doi.org/10.3390/met9030285>
- [133] Colombo, T. C. A., Rego, R. R., Otubo, J., de Faria, A. R. "Mechanical reliability of TWIP steel spot weldings", *Journal of Materials Processing Technology*, 266, pp. 662–674, 2019.
<https://doi.org/10.1016/j.jmatprotec.2018.11.021>

- [134] Paveebunvipak, K., Uthaisangasuk, V. "Characterization of Static Performance and Failure of Resistance Spot Welds of High-Strength and Press-Hardened Steels", *Journal of Materials Engineering and Performance*, 28(4), pp. 2017–2028, 2019.
<https://doi.org/10.1007/s11665-019-03988-2>
- [135] Aghajani, H., Pouranvari, M. "A pathway to produce strong and tough martensitic stainless steels resistance spot welds", *Science and Technology of Welding and Joining*, 24(3), pp. 185–192, 2019.
<https://doi.org/10.1080/13621718.2018.1483065>
- [136] Li, S., Yang, S., Lu, Q., Luo, H., Tao, W. "A Novel Shim-Assisted Resistance Spot Welding Process to Improve Weldability of Medium-Mn Transformation-Induced Plasticity Steel", *Metallurgical and Materials Transactions B*, 50(1), pp. 1–9, 2019.
<https://doi.org/10.1007/s11663-018-1463-9>
- [137] Tumuluru, M. "4 - Resistance spot welding techniques for advanced high-strength steels" (AHSS), In: Shome, M., Tumuluru, M. (eds.) *Welding and Joining of Advanced High Strength Steels (AHSS)*, Woodhead Publishing, 2015, pp. 55–70. ISBN 978-0-85709-436-0
<https://doi.org/10.1016/B978-0-85709-436-0-00004-7>
- [138] Ighodaro, O. L., Biro, E., Zhou, Y. N. "Comparative effects of Al-Si and galvanized coatings on the properties of resistance spot welded hot stamping steel joints", *Journal of Materials Processing Technology*, 236, pp. 64–72, 2016.
<https://doi.org/10.1016/j.jmatprotec.2016.03.021>
- [139] Mei, L., Yi, J., Yan, D., Liu, J., Chen, G. "Comparative study on CO₂ laser overlap welding and resistance spot welding for galvanized steel", *Materials & Design*, 40, pp. 433–442, 2012.
<https://doi.org/10.1016/j.matdes.2012.04.014>
- [140] Long, X., Khanna, S. K. "Fatigue properties and failure characterization of spot welded high strength steel sheet", *International Journal of Fatigue*, 29(5), pp. 879–886, 2007.
<https://doi.org/10.1016/j.ijfatigue.2006.08.003>
- [141] Dancette, S., Fabrègue, D., Massardier, V., Merlin, J., Dupuy, T., Bouzekri, M. "Investigation of the Tensile Shear fracture of Advanced High Strength Steel spot welds", *Engineering Failure Analysis*, 25, pp. 112–122, 2012.
<https://doi.org/10.1016/j.engfailanal.2012.04.009>
- [142] Chen, R., Lou, M., Li, Y., Carlson, B. E. "Improving weldability of Al-Si coated press hardened steel using stepped current pulse schedule", *Journal of Manufacturing Processes*, 48, pp. 31–43, 2019.
<https://doi.org/10.1016/j.jmapro.2019.10.010>
- [143] Chabok, A., van der Aa, E., Pei, Y. "A study on the effect of chemical composition on the microstructural characteristics and mechanical performance of DP1000 resistance spot welds", *Materials Science and Engineering: A*, 788, 139501, 2020.
<https://doi.org/10.1016/j.msea.2020.139501>
- [144] Sobhani, B.S., Pouranvari, M. "Duplex Stainless Steel/Martensitic Steel Dissimilar Resistance Spot Welding: Microstructure-Properties Relationships", *Welding Journal*, 98(9), pp. 263–s–272-s, 2019.
<https://doi.org/10.29391/2019.98.023>
- [145] Sun, X., Zhang, Q., Wang, S., Han, X., Li, Y., David, S. A. "Effect of adhesive sealant on resistance spot welding of 301L stainless steel", *Journal of Manufacturing Processes*, 51, pp. 62–72, 2020.
<https://doi.org/10.1016/j.jmapro.2020.01.033>
- [146] Ertek Emre, H., Bozkurt, B. "Effect of Cr-Ni coated Cu-Cr-Zr electrodes on the mechanical properties and failure modes of TRIP800 spot weldments", *Engineering Failure Analysis*, 110, 104439, 2020.
<https://doi.org/10.1016/j.engfailanal.2020.104439>
- [147] Son, S. G., Hwang, Y., Lee, C. W., Yoo, J. H., Choi, M. "핫스탬핑 열처리 온도가 Al-10% Si 도금 30MnB5 강의 점용접성에 미치는 영향" (Effect of Hot Stamping Heat Treatment Temperature on Resistance Spot Weldability of Al-10% Si Coated 30MnB5 Steel), *Korean Journal of Metals and Materials*, 57(12), pp. 778–786, 2019. (in Korean)
<https://doi.org/10.3365/KJMM.2019.57.12.778>
- [148] Aydın, H., Tutar, M., Davut, K., Bayram, A. "Elektrik direnç punta kaynağı ile birleştirilen %15 deforme edilmiş TWIP çeliğinde kaynak akımının mikroyapı ve mekanik özellikler üzerindeki etkisi" (Effect of welding current on microstructure and mechanical properties of 15% deformed TWIP steel joined with electrical resistance spot welding), *Journal of the Faculty of Engineering and Architecture of Gazi University*, 35(2), pp. 803–817, 2020. (in Turkish)
<https://doi.org/10.17341/gazimmfd.530292>
- [149] Pizzorni, M., Lertora, E., Mandolino, C., Gambaro, C. "Experimental investigation of the static and fatigue behavior of hybrid ductile adhesive-RSWelded joints in a DP 1000 steel", *International Journal of Adhesion and Adhesives*, 95, 102400, 2019.
<https://doi.org/10.1016/j.ijadhadh.2019.102400>
- [150] Subramanian, A., Senthil, P. V., Jabbaraj, D. B., Devakumar, D. "Improving mechanical performance of resistance spot welded joints of AISI 409M steel by double pulse current", *Materials Today: Proceedings*, 16, pp. 949–955, 2019.
<https://doi.org/10.1016/j.matpr.2019.05.181>
- [151] Sivaraj, P., Seeman, M., Kanagarajan, D., Seetharaman, R. "Influence of welding parameter on mechanical properties and microstructural features of resistance spot welded dual phase steel sheets joint", *Materials Today: Proceedings*, 22, pp. 558–562, 2020.
<https://doi.org/10.1016/j.matpr.2019.08.201>
- [152] Shah, U. H., Liu, X. "Ultrasonic resistance welding of TRIP-780 steel", *Journal of Materials Processing Technology*, 274, 116287, 2019.
<https://doi.org/10.1016/j.jmatprotec.2019.116287>
- [153] Sun, X., Stephens, E. V., Khaleel, M. A. "Effects of fusion zone size and failure mode on peak load and energy absorption of advanced high strength steel spot welds under lap shear loading conditions", *Engineering Failure Analysis*, 15(4), pp. 356–367, 2008.
<https://doi.org/10.1016/j.engfailanal.2007.01.018>
- [154] Ren, D., Zhao, D., Zhao, K., Liu, L., He, Z. "Resistance ceramic-filled annular welding of DP980 high-strength steel", *Materials & Design*, 183, 108118, 2019.
<https://doi.org/10.1016/j.matdes.2019.108118>
- [155] Ghatei Kalashami, A., Han, X., Goodwin, F., Zhou, N. Y. "The influence of modified annealing during the galvanizing process on the resistance spot welding of the CMn1.8Si advanced high strength steel", *Surface and Coatings Technology*, 381, 125181, 2020.
<https://doi.org/10.1016/j.surfcoat.2019.125181>

- [156] Mohamadizadeh, A., Biro, E., Worswick, M., Zhou, N., Malcolm, S., Yau, C., Jiao, Z., Chan, K. "Spot Weld Strength Modeling and Processing Maps for Hot-Stamping Steels", *Welding Journal*, 98(8), pp. 241-s–249-s, 2019.
<https://doi.org/10.29391/2019.98.021>
- [157] Vijayan, V., Murugan, S. P., Son, S.-G., Park, Y.-D. "Shrinkage Void Formation in Resistance Spot Welds: Its Effect on Advanced High-Strength-Steel Weld Strength and Failure Modes", *Journal of Materials Engineering and Performance*, 28(12), pp. 7514–7526, 2019.
<https://doi.org/10.1007/s11665-019-04465-6>
- [158] Chao, Y. J. "Ultimate Strength and Failure Mechanism of Resistance Spot Weld Subjected to Tensile, Shear, or Combined Tensile/Shear Loads", *Journal of Engineering Materials and Technology*, 125(2), pp. 125–132, 2003.
<https://doi.org/10.1115/1.1555648>
- [159] Qi, L., Li, F., Chen, R., Zhang, Q., Li, Y. "Improve resistance spot weld quality of advanced high strength steels using bilateral external magnetic field", *Journal of Manufacturing Processes*, 52, pp. 270–280, 2020.
<https://doi.org/10.1016/j.jmapro.2020.02.030>
- [160] Yao, Z., Omiya, M., Ma, N., Nishi, S., Takada, K., Okato, K., Oide, K., Kobayashi, T., Han, J., Terada, K. "Local mechanical characterization and fracture prediction modeling for resistance spot-welded joints of advanced high-strength steel", *Materials Today Communications*, 36, 106787, 2023.
<https://doi.org/10.1016/j.mtcomm.2023.106787>
- [161] Vargas Cortés, V. H., Altamirano Guerrero, G., Mejía Granados, I., Baltazar Hernández, V. H., Maldonado Zepeda, C. "Effect of Retained Austenite and Non-Metallic Inclusions on the Mechanical Properties of Resistance Spot Welding Nuggets of Low-Alloy TRIP Steels", *Metals*, 9(10), 1064, 2019.
<https://doi.org/10.3390/met9101064>
- [162] Zhang, Y., Guo, J., Li, Y., Luo, Z., Zhang, X. "A comparative study between the mechanical and microstructural properties of resistance spot welding joints among ferritic AISI 430 and austenitic AISI 304 stainless steel", *Journal of Materials Research and Technology*, 9(1), pp. 574–583, 2020.
<https://doi.org/10.1016/j.jmrt.2019.10.086>
- [163] Pouranvari, M., Marashi, S. P. H. "Dissimilar Spot Welds of AISI 304/AISI 1008: Metallurgical and Mechanical Characterization", *steel research international*, 82(12), pp. 1355–1361, 2011.
<https://doi.org/10.1002/srin.201100139>
- [164] Zhou, L., Xia, Y.-J., Shen, Y., Haselhuhn, A. S., Wegner, D. M., Li, Y.-B., Carlson, B. E. "Comparative study on resistance and displacement based adaptive output tracking control strategies for resistance spot welding", *Journal of Manufacturing Processes*, 63, pp. 98–108, 2021.
<https://doi.org/10.1016/j.jmapro.2020.03.061>
- [165] Chen, T., Ling, Z., Wang, M., Kong, L. "Effect of a slightly concave electrode on resistance spot welding of Q&P1180 steel", *Journal of Materials Processing Technology*, 285, 116797, 2020.
<https://doi.org/10.1016/j.jmatprotec.2020.116797>
- [166] Chen, T., Ling, Z., Wang, M., Kong, L. "Effect of post-weld tempering pulse on microstructure and mechanical properties of resistance spot welding of Q&P1180 steel", *Materials Science and Engineering: A*, 831, 142164, 2022.
<https://doi.org/10.1016/j.msea.2021.142164>
- [167] Kwon, K., Jang, G., Kim, W., Uhm, S., Lee, T., Lee, C. S. "Effect of type-C liquid metal embrittlement on mechanical properties of spot-welded TRIP steel", *Journal of Materials Research and Technology*, 13, pp. 2482–2490, 2021.
<https://doi.org/10.1016/j.jmrt.2021.06.041>
- [168] Ghatei-Kalashami, A., Zhang, S., Shojaei, M., Midawi, A. R. H., Goodwin, F., Zhou, N. Y. "Failure behavior of resistance spot welded advanced high strength steel: The role of surface condition and initial microstructure", *Journal of Materials Processing Technology*, 299, 117370, 2022.
<https://doi.org/10.1016/j.jmatprotec.2021.117370>
- [169] Mohammed, H. G., Ginta, T. L., Mustapha, M. "The investigation of microstructure and mechanical properties of resistance spot welded AISI 316L austenitic stainless steel", *Materials Today: Proceedings*, 46, pp. 1640–1644, 2021.
<https://doi.org/10.1016/j.matpr.2020.07.258>
- [170] Pouranvari, M. "Susceptibility to interfacial failure mode in similar and dissimilar resistance spot welds of DP600 dual phase steel and low carbon steel during cross-tension and tensile-shear loading conditions", *Materials Science and Engineering: A*, 546, pp. 129–138, 2012.
<https://doi.org/10.1016/j.msea.2012.03.040>
- [171] Mukhopadhyay, G., Bhattacharya, S., Ray, K. K. "Strength assessment of spot-welded sheets of interstitial free steels", *Journal of Materials Processing Technology*, 209(4), pp. 1995–2007, 2009.
<https://doi.org/10.1016/j.jmatprotec.2008.04.065>
- [172] Pandya, K. S., Grolleau, V., Roth, C. C., Mohr, D. "Fracture response of resistance spot welded dual phase steel sheets: Experiments and modeling", *International Journal of Mechanical Sciences*, 187, 105869, 2020.
<https://doi.org/10.1016/j.ijmecsci.2020.105869>
- [173] Rajarajan, C., Sivaraj, P., Seeman, M., Balasubramanian, V. "Influence of electrode force on metallurgical studies and mechanical properties of resistance spot welded dual phase (DP800) steel joints", *Materials Today: Proceedings*, 22, pp. 614–618, 2020.
<https://doi.org/10.1016/j.matpr.2019.09.009>
- [174] Wang, B., Duan, Q. Q., Yao, G., Pang, J. C., Li, X. W., Wang, L., Zhang, Z. F. "Investigation on fatigue fracture behaviors of spot welded Q&P980 steel", *International Journal of Fatigue*, 66, pp. 20–28, 2014.
<https://doi.org/10.1016/j.ijfatigue.2014.03.004>
- [175] Shojaei, M., Midawi, A. R. H., Barber, B., Ghassemi-Armaki, H., Worswick, M., Biro, E. "Mechanical properties and failure behavior of resistance spot welded third-generation advanced high strength steels", *Journal of Manufacturing Processes*, 65, pp. 364–372, 2021.
<https://doi.org/10.1016/j.jmapro.2021.03.047>
- [176] Badkoobeh, F., Nouri, A., Hassannejad, H., Mostaan, H. "Microstructure and mechanical properties of resistance spot welded dual-phase steels with various silicon contents", *Materials Science and Engineering: A*, 790, 139703, 2020.
<https://doi.org/10.1016/j.msea.2020.139703>
- [177] Ravichandran, P., Anbu, C., Meenakshipriya, B., Sathiyavathi, S. "Process parameter optimization and performance comparison of AISI 430 and AISI 1018 in resistance spot welding process", *Materials Today: Proceedings*, 33, pp. 3389–3393, 2020.
<https://doi.org/10.1016/j.matpr.2020.05.197>

- [178] Jaber, H. L., Pouranvari, M., Salim, R. K., Hashim, F. A., Marashi, S. P. H. "Peak load and energy absorption of DP600 advanced steel resistance spot welds", *Ironmaking & Steelmaking*, 44(9), pp. 699–706, 2017.
<https://doi.org/10.1080/03019233.2016.1229880>
- [179] Tumuluru, M. D. "A Comparative Examination of the Resistance Spot Welding Behavior of Two Advanced High Strength Steels", SAE International, Warrendale, PA, USA, SAE Technical Paper 2006-01-1214, 2006. ISBN 0-7680-1634-7
<https://doi.org/10.4271/2006-01-1214>
- [180] Wohner, M., Mitzschke, N., Jüttner, S. "Resistance spot welding with variable electrode force—development and benefit of a force profile to extend the weldability of 22MnB5+AS150", *Welding in the World*, 65(1), pp. 105–117, 2021.
<https://doi.org/10.1007/s40194-020-01001-2>
- [181] Panza, L., Maddis, M. D., Spena, P. R. "Use of electrode displacement signals for electrode degradation assessment in resistance spot welding", *Journal of Manufacturing Processes*, 76, pp. 93–105, 2022.
<https://doi.org/10.1016/j.jmapro.2022.01.060>
- [182] Rezayat, H., Ghassemi-Armaki, H., Sriram, S., Babu, S. S. "Correlation of Local Constitutive Properties to Global Mechanical Performance of Advanced High-Strength Steel Spot Welds", *Metallurgical and Materials Transactions A*, 51(5), pp. 2209–2221, 2020.
<https://doi.org/10.1007/s11661-020-05714-3>
- [183] Hajiannia, I., Shamanian, M., Atapour, M., Ashiri, R. "Evaluation of Weldability and Mechanical Properties in Resistance Spot Welding of Ultrahigh-Strength TRIP1100 Steel", *SAE International Journal of Materials and Manufacturing*, 12(1), pp. 5–18, 2019.
<https://doi.org/10.4271/05-12-01-0001>
- [184] Ma, Y., Takikawa, A., Nakanishi, J., Doira, K., Shimizu, T., Lu, Y., Ma, N. "Measurement of local material properties and failure analysis of resistance spot welds of advanced high-strength steel sheets", *Materials & Design*, 201, 109505, 2021.
<https://doi.org/10.1016/j.matdes.2021.109505>
- [185] Zhang, Y., Fu, C., Yi, R., Ju, J. "Optimization of Double-pulse Process in Resistance Spot Welding of Hot Stamped Steel Sheet", *ISIJ International*, 60(6), pp. 1284–1290, 2020.
<https://doi.org/10.2355/isijinternational.ISIJINT-2019-579>
- [186] Ashiri, R., Marashi, S. P. H., Park, Y.-D. "Weld Processing and Mechanical Responses of 1-GPa TRIP Steel Resistance Spot Welds", *Welding Journal*, 97(5), pp. 157-s–169-s, 2018.
<https://doi.org/10.29391/2018.97.014>
- [187] Arabi, S. H., Pouranvari, M., Movahedi, M. "Welding Metallurgy of Duplex Stainless Steel during Resistance Spot Welding", *Welding Journal*, 96(9), pp. 307-s–318-s, 2017.
- [188] Aghajani, H., Pouranvari, M. "Influence of *In Situ* Thermal Processing Strategies on the Weldability of Martensitic Stainless Steel Resistance Spot Welds: Effect of Second Pulse Current on the Weld Microstructure and Mechanical Properties", *Metallurgical and Materials Transactions A*, 50, pp. 5191–5209, 2019.
<https://doi.org/10.1007/s11661-019-05443-2>
- [189] Hajiannia, I., Shamanian, M., Atapour, M., Ashiri, R., Ghassemali, E. "The Assessment of Second Pulse Effects on the Microstructure and Fracture Behavior of the Resistance Spot Welding in Advanced Ultrahigh-Strength Steel TRIP1100", *Iranian Journal of Materials Science and Engineering*, 16(2), pp. 79–88, 2019.
<https://doi.org/10.22068/ijmse.16.2.79>
- [190] Siar, O., Dancette, S., Dupuy, T., Fabrègue, D. "Impact of liquid metal embrittlement inner cracks on the mechanical behavior of 3rd generation advanced high strength steel spot welds", *Journal of Materials Research and Technology*, 15, pp. 6678–6689, 2021.
<https://doi.org/10.1016/j.jmrt.2021.11.100>
- [191] Ma, Y., Yu, Y., Geng, P., Ihara, R., Maeda, K., Suzuki, R., Suga, T., Ma, N. "Fracture modeling of resistance spot welded ultra-high-strength steel considering the effect of liquid metal embrittlement crack", *Materials & Design*, 210, 110075, 2021.
<https://doi.org/10.1016/j.matdes.2021.110075>
- [192] Ghanbari, H. R., Shariati, M., Sanati, E., Masoudi Nejad, R. "Effects of spot welded parameters on fatigue behavior of ferrite-martensite dual-phase steel and hybrid joints", *Engineering Failure Analysis*, 134, 106079, 2022.
<https://doi.org/10.1016/j.engfailanal.2022.106079>
- [193] Siar, O., Dancette, S., Adrien, J., Dupuy, T., Fabrègue, D. "3D characterization of the propagation of liquid metal embrittlement inner cracks during tensile shear testing of resistance spot welds", *Materials Characterization*, 184, 111664, 2022.
<https://doi.org/10.1016/j.matchar.2021.111664>
- [194] Ma, B.-h., Ma, D.-f., Wang, H.-r., Chen, D.-n., Zhou, F.-h. "Ballistic impact response of resistance-spot-welded (RSW) double-layered plates for Q&P980 steel", *Defence Technology*, 18(6), pp. 1052–1064, 2022.
<https://doi.org/10.1016/j.dt.2021.04.010>
- [195] Wan, X., Wang, Y., Fang, C. "Welding Defects Occurrence and Their Effects on Weld Quality in Resistance Spot Welding of AHSS Steel", *ISIJ International*, 54(8), pp. 1883–1889, 2014.
<https://doi.org/10.2355/isijinternational.54.1883>
- [196] Kitamura, T., Akiyama, T., Masuda, Y. "硬化領域新成による抵抗スポット溶接重ね継手の高強度化" (Strengthening of Spot Welded Lap Joints by New Hardened Zone), *Quarterly Journal of the Japan Welding Society*, 31(2), pp. 89–95, 2013. (in Japanese)
<https://doi.org/10.2207/qjjws.31.89>
- [197] Fujimoto, H., Yasuyama, M., Ueda, H., Ueji, R., Fujii, H. "ホットスタンプ処理されたスポット溶接継手の静的強度特性 — スポット溶接テーラードブランク技術の検討 —" (Static strength of hot-stamped spot welded joints - Study on spot welding tailored blank technology), *Quarterly Journal of the Japan Welding Society*, 33(2), pp. 144–152, 2015. (in Japanese)
<https://doi.org/10.2207/qjjws.33.144>
- [198] Jong, Y.-S., Lee, Y.-K., Kim, D.-C., Kang, M.-J., Hwang, I.-S., Lee, W.-B. "Microstructural Evolution and Mechanical Properties of Resistance Spot Welded Ultra High Strength Steel Containing Boron", *Materials Transactions*, 52(6), pp. 1330–1333, 2011.
<https://doi.org/10.2320/matertrans.M2011005>
- [199] Furukawa, K., Katoh, M., Nishio, K., Yamaguchi, T. "Influence of Electrode Pressure and Welding Conditions on the Maximum Tensile Shear Load — Study on the Development of Electrode Force Changeable Lap Resistance Spot Welding Machine and Characteristics of Welds (Report 2) —", *Quarterly Journal of the Japan Welding Society*, 24(1), pp. 10–16, 2006.
<https://doi.org/10.2207/qjjws.24.10>

- [200] Otani, T., Sasabe, K. "超微細粒高強度鋼板のスポット溶接特性" (Characteristics of Resistance Spot Welds of Ultra-fine Grained High Strength Steel Sheets), Quarterly Journal of the Japan Welding Society, 21(2), pp. 243–248, 2003. (in Japanese)
<https://doi.org/10.2207/qjws.21.243>
- [201] Wan, X., Wang, Y., Zhang, P. "Effects of Welding Schedules on Resistance Spot Welding of DP600 Steel", ISIJ International, 54(10), pp. 2375–2379, 2014.
<https://doi.org/10.2355/isijinternational.54.2375>
- [202] Xie, L., Shi, B., Xiao, Z., Ren, J., Li, D. "Fatigue Characteristics of DP780 Steel Spot Welding Joints with Different Static Fracture Modes", Materials Transactions, 62(2), pp. 191–197, 2021.
<https://doi.org/10.2320/matertrans.MT-M2020214>
- [203] Zhong, N., Liao, X., Wang, M., Wu, Y., Rong, Y. "Improvement of Microstructures and Mechanical Properties of Resistance Spot Welded DP600 Steel by Double Pulse Technology", Materials Transactions, 52(12), pp. 2143–2150, 2011.
<https://doi.org/10.2320/matertrans.M2011135>
- [204] Emre, H. E., Kaçar, R. "Resistance Spot Weldability of Deformed TRIP800 Steel", Welding Journal, 95(3), pp. 77-s–85-s, 2016.
- [205] Silva, D. F., Brito, P. P. "Electrochemical Behavior of Dissimilar Carbon-Stainless Steel RSW Joints", Welding Journal, 2020(1), pp. 1-s–7-s, 2020.
<https://doi.org/10.29391/2020.99.001>
- [206] Pouranvari, M., Marashi, S. P. H. "Failure Mode Transition in AISI 304 Resistance Spot Welds", Welding Journal, 91(11), pp. 303-s–309-s, 2012.
- [207] Li, Y. B., Li, Y. T., Shen, Q., Lin, Z. Q. "Magnetically Assisted Resistance Spot Welding of Dual-Phase Steel", Welding Journal, 92(4), pp. 124-s–132-s, 2013.
- [208] ArcelorMittal "Arcelor Mittal product information homepage", [online] Available at: <https://automotive.arcelormittal.com/home> [Accessed: 29 March 2022]
- [209] Furusako, S., Watanabe, F., Murayama, G., Hamatani, H., Oikawa, H., Takahashi, Y., Nose, T. "Current Problems and the Answer Techniques in Welding Technique of Auto Bodies — First Part", Nippon Steel Technical Report, 103, pp. 69–75, 2013.
- [210] Taniguchi, K., Okita, Y., Ikeda, R. "Development of Next Generation Resistance Spot Welding Technologies Improving the Weld Properties of Advanced High Strength Steel Sheets", JFE Technical Report, 20, pp. 85–91, 2015.
- [211] Wilson, R. B., Fine, T. E. "Fatigue Behavior of Spot Welded High Strength Steel Joints", SAE International, Warrendale, PA, USA, SAE Technical Paper 810354, 1981.
<https://doi.org/10.4271/810354>
- [212] Taniguchi, K., Matsuda, H., Ikeda, R., Oi, K. "Resistance Spot Welding Process with Pulsed Current Pattern to improve Joint Strength of Ultra High Strength Steel Sheets", SAE International, Warrendale, PA, USA, SAE Technical Paper 2015-01-0705, 2015.
<https://doi.org/10.4271/2015-01-0705>
- [213] Girvin, B., Peterson, W., Gould, J. "Development of Appropriate Spot Welding Practice for Advanced High Strength Steels", American Iron and Steel Institute, Pittsburgh, PA, USA, EWI Project No. 47819GTH, 2004.
<https://doi.org/10.2172/840947>
- [214] Shi, G., Westgate, S. A. "Techniques for improving the weldability of TRIP steel using resistance spot welding", In: 1st International Conference Super-high Strength Steels, Rome, Italy, 2005, 89. ISBN 88-85298-56-7
- [215] Taniguchi, K., Matsuda, H., Ikeda, R., Oi, K. "Heat distribution in welds by short-time high-current post-heating and its improving effect on cross tension strength: development of resistance spot welding with pulsed current pattern for ultrahigh-strength steel sheets", Welding International, 30(11), pp. 817–825, 2016.
<https://doi.org/10.1080/09507116.2016.1142194>
- [216] Jing, Y., Xu, Y., Wang, D., Lu, L., Li, J., Yu, Y. "Improving mechanical properties of welds through tailoring microstructure characteristics and fracture mechanism in multi-pulse resistance spot welding of Q&P980 steel", Materials Science and Engineering: A, 143130, 2022.
<https://doi.org/10.1016/j.msea.2022.143130>
- [217] Shojaei, M., Tolton, C., Midawi, A. R. H., Butcher, C., Ghassemi-Armaki, H., Worswick, M., Biro, E. "Influence of loading orientation on mechanical properties of spot welds", International Journal of Mechanical Sciences, 224, 107327, 2022.
<https://doi.org/10.1016/j.ijmecsci.2022.107327>
- [218] Mohamadizadeh, A., Biro, E., Worswick, M. "Failure characterization and meso-scale damage modeling of spot welds in hot-stamped automotive steels using a hardness-mapping approach", Engineering Fracture Mechanics, 268, 108506, 2022.
<https://doi.org/10.1016/j.engfracmech.2022.108506>
- [219] Rajak, B., Kishore, K., Mishra, V. "Investigation of a novel TIG-spot welding vis-à-vis resistance spot welding of dual-phase 590 (DP 590) steel: Processing-microstructure-mechanical properties correlation", Materials Chemistry and Physics, 296, 127254, 2023.
<https://doi.org/10.1016/j.matchemphys.2022.127254>
- [220] Dong, W., Lei, M., Pan, H., Ding, K., Gao, Y. "Role of the internal oxidation layer in the liquid metal embrittlement during the resistance spot welding of the Zn-coated advanced high strength steel", Journal of Materials Research and Technology, 21, pp. 3313–3326, 2022.
<https://doi.org/10.1016/j.jmrt.2022.10.154>
- [221] Tian, J., Tao, W., Yang, S. "Investigation on microhardness and fatigue life in spot welding of quenching and partitioning 1180 steel", Journal of Materials Research and Technology, 19, pp. 3145–3159, 2022.
<https://doi.org/10.1016/j.jmrt.2022.06.083>
- [222] Zhao, D., Vdonin, N., Bezgans, Y., Radionova, L., Bykov, V., Glebov, L. "Mechanical attributes and microstructural characteristics of resistance spot-welded HSLA 420 steel joints", The International Journal of Advanced Manufacturing Technology, 124(10), pp. 3505–3518, 2023.
<https://doi.org/10.1007/s00170-022-10798-9>
- [223] Abd Al Al, S. A., Meilinger, Á. "Development of resistance spot welding technology on ultra-high strength steel sheets", In: Gáti, J. (ed.) XXXI. Nemzetközi Hegesztési Konferencia, Kecskemét, Hungary, 2022, pp. 113–123. ISBN 978-615-6260-01-7
- [224] Tutar, M., Aydın, H., Bayram, A. "Effect of Weld Current on the Microstructure and Mechanical Properties of a Resistance Spot-Welded TWIP Steel Sheet", Metals, 7(12), 519, 2017.
<https://doi.org/10.3390/met7120519>

- [225] Pawar, S., Singh, A. K., Park, K.-S., Choi, S.-H. "Effect of welding current on the microstructural evolution and lap-shear performance of resistance spot-welded 340BH steel", *Materials Characterization*, 203, 113126, 2023.
<https://doi.org/10.1016/j.matchar.2023.113126>
- [226] Amini-Chelak, M. H., Miresmaeili, R., Askari-Paykani, M., Aliyari, H., Shahverdi, H. R. "Resistance spot weldability of Fe₆₆Cr_{16.5}Ni_{14.1}Si_{3.4} advanced high strength steel using D-optimal design of experiment method", *Journal of Materials Research and Technology*, 25, pp. 5615–5632, 2023.
<https://doi.org/10.1016/j.jmrt.2023.06.262>
- [227] Şahin, S., Hayat, F., Çölgeçen, O. C. "The effect of welding current on nugget geometry, microstructure and mechanical properties of TWIP steels in resistance spot welding", *Welding in the World*, 65(5), pp. 921–935, 2021.
<https://doi.org/10.1007/s40194-021-01083-6>
- [228] Figueredo, B., Ramachandran, D. C., Macwan, A., Biro, E. "Failure behavior and mechanical properties in the resistance spot welding of quenched and partitioned (Q&P) steels", *Welding in the World*, 65(12), pp. 2359–2369, 2021.
<https://doi.org/10.1007/s40194-021-01179-z>
- [229] Sarmast-Ghahfarokhi, S., Zhang, S., Midawi, A. R. H., Goodwin, F., Zhou, Y. N. "Mechanical properties and failure behavior of resistance spot welded medium-Mn steel under static and quasi-static shear-tension loading", *Welding in the World*, 66(8), pp. 1609–1622, 2022.
<https://doi.org/10.1007/s40194-022-01314-4>
- [230] Tanegashima, R., Akebono, H., Kato, M., Miyagaki, A., Sugeta, A. "3-Dimensional Observation of Fatigue Crack Propagation on Spot Welded Joints using High Strength Steel", *International Journal of Automotive Engineering*, 2(3), pp. 61–67, 2011.
https://doi.org/10.20485/jsaeijae.2.3_61
- [231] Okada, T., Ueda, H., Matsuda, K., Miyazaki, Y., Yasuyama, M., Fujii, H. "異強度板組の抵抗スポット溶接継手の引張せん断強さと破断位置に及ぼす材料強度の影響" (Effect of strength of steel sheets on tensile shear strength and failure mode of dissimilar joint of spot welds), *Quarterly Journal of the Japan Welding Society*, 40(4), pp. 216–225, 2022. (in Japanese)
<https://doi.org/10.2207/qjwjs.40.216>
- [232] Pollard, B. "Spot welding characteristics of HSLA steel for automotive applications", *Welding Journal*, 53(8), pp. 343–s–350-s, 1974.
- [233] Miller, C. C. E. "The joining of advanced high strength steels using resistance spot welding", PhD Thesis, Swansea University, 2008. ProQuest 10797960
- [234] Ha, J., Huh, H., Lee, H., Kim, K. S. "Failure Characteristics of Spot Welds of AHSS under Quasi-static Conditions", In: Proulx, T. (ed.) *Experimental and Applied Mechanics*, Volume 6, Springer, 2011, pp. 623–629. ISBN 978-1-4614-0221-3
https://doi.org/10.1007/978-1-4614-0222-0_74
- [235] Akiyama, T., Kitamura, T., Ono, T. "Dependence of Load Angle on Static Strength of Resistance Spot Welded Lap Joint under Combined Load Test", *Materials Transactions*, 59(8), pp. 1275–1279, 2018.
<https://doi.org/10.2320/matertrans.M2018028>
- [236] Mukhopadhyay, G., Bhattacharya, S., Ray, K. K. "Effect of pre-strain on the strength of spot-welds", *Materials & Design*, 30(7), pp. 2345–2354, 2009.
<https://doi.org/10.1016/j.matdes.2008.11.006>
- [237] Fadaei, A., Mahmoudi, A. H., Borzuie, A. "Experimental Study of the Nugget Diameter Effect on Tensile-Shear Strength in AISI 1008 Spot Welding Specimens", *Journal of Mechanical Research and Application*, 4(1), pp. 1–7, 2012.
- [238] Song, J. H., Huh, H. "Failure characterization of spot welds under combined axial-shear loading conditions", *International Journal of Mechanical Sciences*, 53(7), pp. 513–525, 2011.
<https://doi.org/10.1016/j.ijmecsci.2011.04.008>
- [239] Al-Mukhtar, A. M., Doos, Q. "The Spot Weldability of Carbon Steel Sheet", *Advances in Materials Science and Engineering*, 2013, 146896, 2013.
<https://doi.org/10.1155/2013/146896>
- [240] Chtourou, R., Leconte, N., Chaari, F., Haugou, G., Markiewicz, É., Zouari, B. "Macro-modeling of the strength and failure of multi-layer multi-steel grade spot welds: Connector formulation, assembly model and identification procedure", *Thin-Walled Structures*, 113, pp. 228–239, 2017.
<https://doi.org/10.1016/j.tws.2017.01.023>
- [241] Chen, J., Yuan, X., Hu, Z., Li, T., Wu, K., Li, C. "Improvement of resistance-spot-welded joints for DP 600 steel and A5052 aluminum alloy with Zn slice interlayer", *Journal of Manufacturing Processes*, 30, pp. 396–405, 2017.
<https://doi.org/10.1016/j.jmapro.2017.10.009>
- [242] den Uijl, N., Smith, S., Moolevliet, T., Goos, C., van der Aa, E., van der Veldt, T. "Failure modes of resistance spot welded advanced high strength steels", In: Zhang, W., Scotchmer, N. (eds.) *The 5th International Seminar on Advances in Resistance Welding*, Toronto, Canada, 2008, pp. 78–104.
<https://doi.org/10.13140/RG.2.1.1321.8165>
- [243] Russo Spena, P., Rossi, S., Wurzer, R. "Effects of Welding Parameters on Strength and Corrosion Behavior of Dissimilar Galvanized Q&P and TRIP Spot Welds", *Metals*, 7(12), 534, 2017.
<https://doi.org/10.3390/met7120534>
- [244] Spena, P. R., De Maddis, M., Lombardi, F. "Mechanical Strength and Fracture of Resistance Spot Welded Advanced High Strength Steels", *Procedia Engineering*, 109, pp. 450–456, 2015.
<https://doi.org/10.1016/j.proeng.2015.06.262>
- [245] Onar, V., Aslanlar, S., Akkas, N. "Effect of welding current on mechanical properties of welding joints in TRIP 800 and micro alloyed steels in resistance spot welding", In: 4th International Conference on Welding Technologies and Exhibition (ICWET'16), Gaziantep, Turkey, 2016, pp. 1–6.
- [246] Pouranvari, M., Mousavizadeh, S. M., Marashi, S. P. H., Goodarzi, M., Ghorbani, M. "Influence of fusion zone size and failure mode on mechanical performance of dissimilar resistance spot welds of AISI 1008 low carbon steel and DP600 advanced high strength steel", *Materials & Design*, 32(3), pp. 1390–1398, 2011.
<https://doi.org/10.1016/j.matdes.2010.09.010>
- [247] Noh, W., Kim, W., Yang, X., Kang, M., Lee, M.-G., Chung, K. "Simple and effective failure analysis of dissimilar resistance spot welded advanced high strength steel sheets", *International Journal of Mechanical Sciences*, 121, pp. 76–89, 2017.
<http://doi.org/10.1016/j.ijmecsci.2016.12.006>
- [248] Yuan, X., Li, C., Chen, J., Li, X., Liang, X., Pan, X. "Resistance spot welding of dissimilar DP600 and DC54D steels", *Journal of Materials Processing Technology*, 239, pp. 31–41, 2017.
<https://doi.org/10.1016/j.jmatprotec.2016.08.012>

- [249] Huin, T., Dancette, S., Fabrègue, D., Dupuy, T. "Investigation of the Failure of Advanced High Strength Steels Heterogeneous Spot Welds", *Metals*, 6(5), 111, 2016.
<https://doi.org/10.3390/met6050111>
- [250] Russo Spena, P., De Maddis, M., D'Antonio, G., Lombardi, F. "Weldability and Monitoring of Resistance Spot Welding of Q&P and TRIP Steels", *Metals*, 6(11), 270, 2016.
<https://doi.org/10.3390/met6110270>
- [251] Russo Spena, P., De Maddis, M., Lombardi, F., Rossini, M. "Dissimilar Resistance Spot Welding of Q&P and TWIP Steel Sheets", *Materials and Manufacturing Processes*, 31(3), pp. 291–299, 2016.
<https://doi.org/10.1080/10426914.2015.1048476>
- [252] Russo Spena, P., Cortese, L., De Maddis, M., Lombardi, F. "Effects of Process Parameters on Spot Welding of TRIP and Quenching and Partitioning Steels", *steel research international*, 87(12), pp. 1592–1600, 2016.
<https://doi.org/10.1002/srin.201600007>
- [253] Choi, H.-S., Park, G.-H., Lim, W.-S., Kim, B.-m. "Evaluation of weldability for resistance spot welded single-lap joint between GA780DP and hot-stamped 22MnB5 steel sheets", *Journal of Mechanical Science and Technology*, 25(6), pp. 1543–1550, 2011.
<https://doi.org/10.1007/s12206-011-0408-x>
- [254] Kim, D., Yu, J., Rhee, S. "Effect of a conically shaped hollow electrode on advanced high strength steel in three-sheet resistance spot welding", *International Journal of Precision Engineering and Manufacturing*, 17(3), pp. 331–336, 2016.
<https://doi.org/10.1007/s12541-016-0041-9>
- [255] Zhang, H., Qiu, X., Bai, Y., Xing, F., Yu, H., Shi, Y. "Resistance spot welding macro characteristics of the dissimilar thickness dual phase steels", *Materials & Design*, 63, pp. 151–158, 2014.
<https://doi.org/10.1016/j.matdes.2014.05.060>
- [256] Alizadeh-Sh, M., Marashi, S. P. H. "Resistance spot welding of dissimilar austenitic/duplex stainless steels: Microstructural evolution and failure mode analysis", *Journal of Manufacturing Processes*, 28, pp. 186–196, 2017.
<https://doi.org/10.1016/j.jmapro.2017.06.005>
- [257] Jaber, H., Kovacs, T. "Dissimilar Resistance Spot Welding of Ferrite-Martensite Dual Phase Steel/Low Carbon Steel: Phase Transformations and Mechanical Properties", In: Jármay, K., Bolló, B. (eds.) *Vehicle and Automotive Engineering 2*, Springer, 2018, pp. 709–718. ISBN 978-3-319-75676-9
https://doi.org/10.1007/978-3-319-75677-6_60
- [258] Mousavi Anijdan, S. H., Sabzi, M., Ghobeiti-Hasab, M., Roshan-Ghiyas, A. "Optimization of spot welding process parameters in dissimilar joint of dual phase steel DP600 and AISI 304 stainless steel to achieve the highest level of shear-tensile strength", *Materials Science and Engineering: A*, 726, pp. 120–125, 2018.
<https://doi.org/10.1016/j.msea.2018.04.072>
- [259] Vignesh, K., Elaya Perumal, A., Velmurugan, P. "Optimization of resistance spot welding process parameters and microstructural examination for dissimilar welding of AISI 316L austenitic stainless steel and 2205 duplex stainless steel", *The International Journal of Advanced Manufacturing Technology*, 93(1–4), pp. 455–465, 2017.
<https://doi.org/10.1007/s00170-017-0089-4>
- [260] Ozturk Yilmaz, I., Bilici, A. Y., Aydin, H. "Microstructure and mechanical properties of dissimilar resistance spot welded DP1000–QP1180 steel sheets", *Journal of Central South University*, 26(1), pp. 25–42, 2019.
<https://doi.org/10.1007/s11771-019-3980-3>
- [261] Liu, C., Zheng, X., He, H., Wang, W., Wei, X. "Effect of work hardening on mechanical behavior of resistance spot welding joint during tension shear test", *Materials & Design*, 100, pp. 188–197, 2016.
<https://doi.org/10.1016/j.matdes.2016.03.120>
- [262] Özsaraç, U., Onar, V., Özen, F., Aslanlar, Y. S., Akkaş, N., Aslan, H., Aslanlar, S. "Effect of welding time on tensile-shear load in resistance spot welded TRIP 800 and microalloyed steels", *Indian Journal of Chemical Technology*, 26(4), pp. 355–357, 2019.
- [263] Janardhan, G., Kishore, K., Mukhopadhyay, G., Dutta, K. "Fatigue Properties of Resistance Spot Welded Dissimilar Interstitial-Free and High Strength Micro-Alloyed Steel Sheets", *Metals and Materials International*, 27(9), pp. 3432–3448, 2021.
<https://doi.org/10.1007/s12540-020-00678-w>
- [264] Yaghoobi, F., Jamaati, R., Aval, H. J. "Resistance spot welding of high-strength DP steel and nano/ultrafine-grained IF steel sheets", *Materials Chemistry and Physics*, 281, 125909, 2022.
<https://doi.org/10.1016/j.matchemphys.2022.125909>
- [265] Chen, L., Zhang, Y., Xue, X., Wang, B., Yang, J., Zhang, Z., Tyrer, N., Barber, G. C. "Investigation on shearing strength of resistance spot-welded joints of dissimilar steel plates with varying welding current and time", *Journal of Materials Research and Technology*, 16, pp. 1021–1028, 2022.
<https://doi.org/10.1016/j.jmrt.2021.12.079>
- [266] Dancette, S., Huin, T., Dupuy, T., Fabrègue, D. "Finite element modeling of deformation and fracture of advanced high strength steels dissimilar spot welds", *Engineering Fracture Mechanics*, 258, 108092, 2021.
<https://doi.org/10.1016/j.engfracmech.2021.108092>
- [267] Bina, M. H., Jamali, M., Shamanian, M., Sabet, H. "Effect of Welding Time in the Resistance Spot Welded Dissimilar Stainless Steels", *Transactions of the Indian Institute of Metals*, 68(2), pp. 247–255, 2015.
<https://doi.org/10.1007/s12666-014-0452-1>
- [268] Khuenkaew, T., Kanlayasiri, K. "Optimizing the resistance spot-welding process for dissimilar stainless steels", *IOP Conference Series: Materials Science and Engineering*, 361, 012005, 2018.
<https://doi.org/10.1088/1757-899x/361/1/012005>
- [269] Khuenkaew, T., Kanlayasiri, K. "Resistance Spot Welding of SUS316L Austenitic/SUS425 Ferritic Stainless Steels: Weldment Characteristics, Mechanical Properties, Phase Transformation and Solidification", *Metals*, 9(6), 710, 2019.
<https://doi.org/10.3390/met9060710>
- [270] Pouranvari, M., Marashi, S. P. H., Alizadeh-Sh, M. "Welding Metallurgy of Dissimilar AISI 430/DQSK Steels Resistance Spot Welds", *Welding Journal*, 94(6), pp. 203–s–210–s, 2015.
- [271] Janardhan, G., Kishore, K., Dutta, K., Mukhopadhyay, G. "Tensile and fatigue behavior of resistance spot-welded HSLA steel sheets: Effect of pre-strain in association with dislocation density", *Materials Science and Engineering: A*, 793, 139796, 2020.
<https://doi.org/10.1016/j.msea.2020.139796>

- [272] Li, X., Liu, W., Liu, H., Zhang, Z., Bao, P. "Microstructure and thermal cracking susceptibility of dissimilar resistance spot welded austenitic and mild steels", *Welding in the World*, 67(2), pp. 417–423, 2023.
<https://doi.org/10.1007/s40194-022-01440-z>
- [273] Ha, J., Huh, H., Song, J. H., Lim, J. H. "Prediction of failure characteristics of spot welds of DP and trip steels with an equivalent strength failure model", *International Journal of Automotive Technology*, 14(1), pp. 67–78, 2013.
<https://doi.org/10.1007/s12239-013-0009-z>
- [274] ISO "ISO 14327:2004 Resistance welding - Procedures for determining the weldability lobe for resistance spot, projection and seam welding", International Organization for Standardization, Geneva, Switzerland, 2004.
- [275] Betiku, O. T., Ramachandran, D. C., Ghatei-Kalashami, A., DiGiovanni, C., Sherepenko, O., Ghassemi-Armaki, H., Biro, E. "Improving the mechanical performance of press-hardened steel resistance-spot welds via in-situ grain refinement", *Journal of Materials Processing Technology*, 320, 118122, 2023.
<https://doi.org/10.1016/j.jmatprotec.2023.118122>
- [276] Amirthalingam, M., van der Aa, E. M., Kwakernaak, C., Hermans, M. J. M., Richardson, I. M. "Elemental segregation during resistance spot welding of boron containing advanced high strength steels", *Welding in the World*, 59(5), pp. 743–755, 2015.
<https://doi.org/10.1007/s40194-015-0250-3>
- [277] Dancette, S., Fabrègue, D., Massardier, V., Merlin, J., Dupuy, T., Bouzekri, M. "Experimental and modeling investigation of the failure resistance of Advanced High Strength Steels spot welds", *Engineering Fracture Mechanics*, 78(10), pp. 2259–2272, 2011.
<https://doi.org/10.1016/j.engfracmech.2011.04.013>
- [278] Chao, Y. J. "Failure mode of spot welds: interfacial versus pullout", *Science and Technology of Welding and Joining*, 8(2), pp. 133–137, 2003.
- [279] Watanabe, G., Amago, T., Ishii, Y., Takao, H., Yasui, T., Fukumoto, M. "Improvement of cross-tension strength using concave electrode in resistance spot welding of high-strength steel sheets", *AIP Conference Proceedings*, 1709(1), 020003, 2016.
<https://doi.org/10.1063/1.4941202>
- [280] Chabok, A., van der Aa, E., De Hosson, J. T. M., Pei, Y. T. "Mechanical behavior and failure mechanism of resistance spot welded DP1000 dual phase steel", *Materials & Design*, 124, pp. 171–182, 2017.
<https://doi.org/10.1016/j.matdes.2017.03.070>
- [281] Smith, S., den Uijl, N. J., Okada, T., van der Veldt, T., Uchihara, M., Fukui, K. "The Effect of Ageing on the Spot Weld Strength of AHSS and the Consequences for Testing Procedures", *Welding in the World*, 54(1–2), pp. R12–R26, 2010.
<https://doi.org/10.1007/BF03263480>
- [282] Park, G., Kim, K., Uhm, S., Lee, C. "A comparison of cross-tension properties and fracture behavior between similar and dissimilar resistance spot-weldments in medium-Mn TRIP steel", *Materials Science and Engineering: A*, 752, pp. 206–216, 2019.
<https://doi.org/10.1016/j.msea.2019.03.023>
- [283] Radakovic, D. J., Tumuluru, M. "An Evaluation of the Cross-Tension Test of Resistance Spot Welds in High-Strength Dual-Phase Steels", *Welding Journal*, 91(1), pp. 8-s–15-s, 2012.
- [284] Ding, K., Wang, Y., Wei, T., Wu, G., Zhang, Y., Pan, H., Gao, Y. "Effect of Post-weld Heat Treatment on the Cross Tensile Strength of Resistance Spot-Welded Medium Manganese Steel", *Journal of Materials Engineering and Performance*, 30(8), pp. 6107–6119, 2021.
<https://doi.org/10.1007/s11665-021-05787-0>
- [285] Zhao, B., Wang, Y., Ding, K., Wu, G., Wei, T., Pan, H., Gao, Y. "Enhanced Cross-Tension Property of the Resistance Spot Welded Medium-Mn Steel by In Situ Microstructure Tailoring", *International Journal of Steel Structures*, 21(2), pp. 666–675, 2021.
<https://doi.org/10.1007/s13296-021-00464-3>
- [286] Kim, D.-H., Kim, H.-K. "Fatigue strength evaluation of cross-tension spot weld joints of cold rolled mild steel sheet", *Materials & Design*, 30(8), pp. 3286–3290, 2009.
<https://doi.org/10.1016/j.matdes.2009.01.002>
- [287] Stadler, M., Schnitzer, R., Gruber, M., Hofer, C. "Improving the mechanical performance of a resistance spot welded 1200 MPa TBF steel", *International Journal of Materials Research*, 112(4), pp. 262–270, 2021.
<https://doi.org/10.1515/ijmr-2020-7962>
- [288] Stadler, M., Schnitzer, R., Gruber, M., Steineder, K., Hofer, C. "Influence of the Cooling Time on the Microstructural Evolution and Mechanical Performance of a Double Pulse Resistance Spot Welded Medium-Mn Steel", *Metals*, 11(2), 270, 2021.
<https://doi.org/10.3390/met11020270>
- [289] Shamsujjoha, M., Enloe, C. M., Chuang, A. C., Coryell, J. J., Ghassemi-Armaki, H. "Mechanisms of paint bake response in resistance spot-welded first and third generation AHSS", *Materialia*, 15, 100975, 2021.
<https://doi.org/10.1016/j.mtla.2020.100975>
- [290] Zhao, B., Wang, Y., Ding, K., Wu, G., Wei, T., Pan, H., Gao, Y. "Role of Intercritical Annealing in Enhancing the Cross-Tension Property of Resistance Spot-Welded Medium Mn Steel", *Journal of Materials Engineering and Performance*, 30(2), pp. 1259–1269, 2021.
<https://doi.org/10.1007/s11665-020-05440-2>
- [291] Tamizi, M., Pouranvari, M., Movahedi, M. "The Role of HAZ Softening on Cross-Tension Mechanical Performance of Martensitic Advanced High Strength Steel Resistance Spot Welds", *Metallurgical and Materials Transactions A*, 52(2), pp. 655–667, 2021.
<https://doi.org/10.1007/s11661-020-06104-5>
- [292] Sherepenko, O., Jüttner, S. "Transient softening at the fusion boundary in resistance spot welded ultra-high strengths steel 22MnB5 and its impact on fracture processes", *Welding in the World*, 63(1), pp. 151–159, 2019.
<https://doi.org/10.1007/s40194-018-0633-3>
- [293] EftekhariMilani, P., van der Aa, E. M., Petrov, R., Hermans, M. J. M., Richardson, I. M. "Understanding the Effect of a Paint Bake Cycle on the Microstructure–Mechanical Properties Relationship of a Resistance Spot Welded Advanced High Strength Steel", *Metallurgical and Materials Transactions A*, 49(12), pp. 6185–6196, 2018.
<https://doi.org/10.1007/s11661-018-4912-9>
- [294] Kitamura, T., Akiyama, T., Asada, M. "抵抗スポット溶接重ね継手十字引張強度のレーザ加熱による高強度化" (Enhancement of Cross-Tension Strength of Resistance Spot-Welded Lap Joints by Laser Heating), *Journal of the Japan Institute of Metals and Materials*, 79(10), pp. 518–522, 2015. (in Japanese)
<https://doi.org/10.2320/jinstmet.J2015029>

- [295] Lin, H. C., Hsu, C. A., Lee, C. S., Kuo, T. Y., Jeng, S. L. "Effects of zinc layer thickness on resistance spot welding of galvanized mild steel", *Journal of Materials Processing Technology*, 251, pp. 205–213, 2018.
<https://doi.org/10.1016/j.jmatprotec.2017.08.035>
- [296] Soomro, I. A., Pedapati, S. R., Awang, M. "Optimization of post-weld tempering pulse parameters for maximum load bearing and failure energy absorption in dual phase (DP590) steel resistance spot welds", *Materials Science and Engineering: A*, 803, 140713, 2021.
<https://doi.org/10.1016/j.msea.2020.140713>
- [297] Ramachandran, D. C., Figueredo, B., Sherepenko, O., Jin, W., Park, Y.-D., Biro, E. "A study on improving the mechanical performance by controlling the halo ring in the Q&P 980 steel resistance spot welds", *Journal of Manufacturing Processes*, 75, pp. 320–330, 2022.
<https://doi.org/10.1016/j.jmapro.2022.01.019>
- [298] Sadasue, T., Handa, T., Taniguchi, K., Tagawa, T., Ikeda, R. "高張力鋼板のスポット溶接継手の破壊挙動に関する板厚の影響及び破壊靱性の支配因子" (Effect of sheet thickness on failure behavior of resistance spot welding joints in high strength steel sheets and dominant factors for fracture toughness), *Quarterly Journal of the Japan Welding Society*, 36(4), pp. 253–263, 2018. (in Japanese)
<https://doi.org/10.2207/qjjws.36.253>
- [299] Bézi, Z., Baptisza, B., Szávai, S. "Experimental and numerical analysis of resistance spot welded joints on DP600 sheets", *Welding and Material Testing*, 23(4), pp. 7–12, 2014.
- [300] Taniguchi, K., Matsuda, H., Ikeda, R. "ナゲット径変動時の十字引張強さに及ぼす短時間・高電流のパルス通電の影響 –超ハイテンのパルス通電活用抵抗スポット溶接技術の開発–" (Influence of pulsed current pattern on cross tension strength of spot welded joint with nugget diameter variation – Development of resistance spot welding with pulsed current pattern for ultra-high strength steel sheets –), *Quarterly Journal of the Japan Welding Society*, 37(4), pp. 215–223, 2019. (in Japanese)
<https://doi.org/10.2207/qjjws.37.215>
- [301] Chabok, A., Cao, H., van der Aa, E., Pei, Y. "New insights into the fracture behavior of advanced high strength steel resistance spot welds", *Journal of Materials Processing Technology*, 301, 117433, 2022.
<https://doi.org/10.1016/j.jmatprotec.2021.117433>
- [302] Sawanishi, C., Ogura, T., Taniguchi, K., Ikeda, R., Oi, K., Yasuda, K., Hirose, A. "Mechanical properties and microstructures of resistance spot welded DP980 steel joints using pulsed current pattern", *Science and Technology of Welding and Joining*, 19(1), pp. 52–59, 2014.
<https://doi.org/10.1179/1362171813Y.0000000165>
- [303] Kondo, T., Ishiuchi, K. "1.2GPa Advanced High Strength Steel with High Formability", SAE International, Warrendale, PA, USA, SAE Technical Paper 2014-01-0991, 2014.
<https://doi.org/10.4271/2014-01-0991>
- [304] Okada, T., Ueda, H., Miyazaki, Y., Yasuyama, M., Fujii, H. "異強度板組の抵抗スポット溶接継手の剥離強度と破断位置に及ぼす材料強度の影響" (Effect of strength of steel sheets on peel tensile strength and failure mode of dissimilar joint of spot welds), *Quarterly Journal of the Japan Welding Society*, 40(4), pp. 226–237, 2022. (in Japanese)
<https://doi.org/10.2207/qjjws.40.226>
- [305] Park, G., Kim, K., Uhm, S., Lee, C. "Remarkable improvement in resistance spot weldability of medium-Mn TRIP steel by paint-baking heat treatment", *Materials Science and Engineering: A*, 766, 138401, 2019.
<https://doi.org/10.1016/j.msea.2019.138401>