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# Resistance of Arc Spot Welds – Update to Provisions

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# Resistance of Arc Spot Welds- Update to Provisions

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## Abstract

The AISI S100-12 provisions for arc spot welds have not be reviewed since 1999. This study performs a comprehensive analysis of the entire arc spot weld data base including data from four new research studies and reconsiders AISI S100-12 resistance equations with data from 450 specimens. Most AISI S100-12 equations were found to be conservative, particularly for sheet tearing failure modes. However, the equation for arc spot weld fracture under tensile load was found to poorly predict the data base test results. AISI S100-12 provision improvements are recommended not only for the resistance equations and factors, but also for the effective weld diameter calculation, maximum sheet thickness limitation, and design approaches for various sheet configurations.

## Introduction

Over the course of seventeen years, four new research studies have significantly expanded the data base of laboratory tested arc spot welds since the last AISI comprehensive review performed in 1999. This study performed a comprehensive analysis of the expanded data base to re-evaluate the arc spot weld design provisions provided in AISI S100-12. Re-evaluation of both the arc spot weld resistance equations and their associated resistance and safety factors was performed.

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Data was gathered starting from Fung's 1978 report, "Strength of Arc Spot Weld in Sheet Steel Construction" which included 127 shear tests and 128 tension tests on arc spot welds and Pekoz and McGuire's 1979 report, "Welding of Sheet Steel", which tested 126 arc spot weld specimens under shear loading. These early reports included simple configurations such as one to two sheet layers. In 1991 LaBoube and Yu expanded arc spot weld tension tests with 260 specimens in their report, "Tensile Strength of Welded Connections" by testing various sheet configurations such as side lapped sheets and eccentrically loaded samples to simulate perimeter roof welds subject to uplift. These three reports composed the 1999 data base of which the AISI S100-12 arc spot weld provisions are based.

The first report to publish following the 1999 comprehensive review was "Inelastic Response of Arc Spot Weld Deck to Frame Connections for Steel Roof Deck Diaphragms", by Peuler in 2002. Peuler explored the performance of arc spot welds under monotonic and seismic shear loading both with and without weld washers creating and testing 235 specimens. In 2008 Easterling and Snow published their report, "Strength of Arc Spot Welds Made in Single and Multiple Steel Sheets" testing 138 shear loaded specimens. Easterling and Snow explored the effects of limited welding time and arc spot welds made through up to four sheet layers. Also in 2008, LaBoube and Stirnemann created and tested 79 specimens subject simultaneously to shear and tensile forces in their report, "Behavior of Arc Spot Weld Connections Subjected to Combined Shear and Tension Forces". Rounding out the existing arc spot weld data base are 179 specimens from Guenfoud's 2010 report, "Experimental Program on the Shear Capacity and Tension Capacity of Arc Spot Weld Connections for Multi-Overlap Roof Deck Panels". Guenfoud considered every sheet configuration practiced in today's steel deck construction including two sheet side laps, and four sheet side laps.

From research performed through the 1970s to 2010 the arc spot weld data base consists of over 1,200 specimens. Of these specimens this study focused on only those made with full welding time, proper weld penetration, without weld washers, under monotonic shear or tension loading. Specimens that were made with washers, were loaded under cyclic, seismic, or combined forces, or had pertinent data missing from their respective reports were not included here. The remaining specimens, 450 total, were then categorized by failure mode to assess the AISI S100-12 provisions. AISI S100-12 arc spot design Equations E2.2.2.1-1, E2.2.2.1-2, E2.2.2.1-3, E2.2.2.1-4, E2.2.2.1-5, E2.2.3-1 and E2.2.3-2 were assessed in addition to the Section E2.2 sheet thickness limitation of 0.15 inches (3.81mm).

## Analysis and Results Highlights

### Effective Weld Diameter

Effective weld diameter, $d_e$, is the diameter of the arc spot weld located at the plane of failure. Effective weld diameter is used to calculate the weld resistance in both shear and tension calculations. Below lists AISI S100-12 Equation E2.2.2.1-5 specified for the calculation effective weld diameter, where d, is the visual diameter of the weld from the top sheet surface and t, is the combined sheet thickness.

E2.2.2.1-5: $d_e = 0.7d - 0.15t \leq 0.55d$

This equation is based on Pekoz's work in the 1970's. In a 2016 unpublished report by Church and Bogh, "Reevaluation of AISI Effective Diameter Equations for Arc Spot Welds" the authors demonstrate that Pekoz's data aligns with the Equation E2.2.2.1-5 and its 0.55d maximum limit, shown by the lines in Figure 1 below.

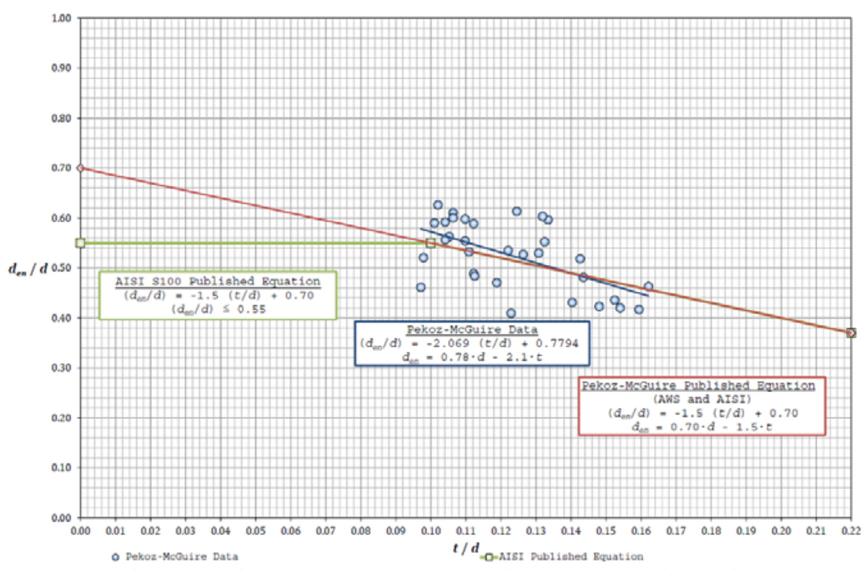

Figure 1: Pekoz Effective Weld Diameter Data (Church and Bogh, 2016).

Since Pekoz's work, additional authors such as Easterling and Snow, and Guenfoud have also measured effective weld diameter data. This study complied the entire shear data base to produced Figure 2 below. It is observed that several data points from Easterling and Snow as well as Guenfoud expanded the thickness and weld diameter ranges tested compared to Pekoz and that the 0.55d limit (horizontal line) does not apply to this expanded database.

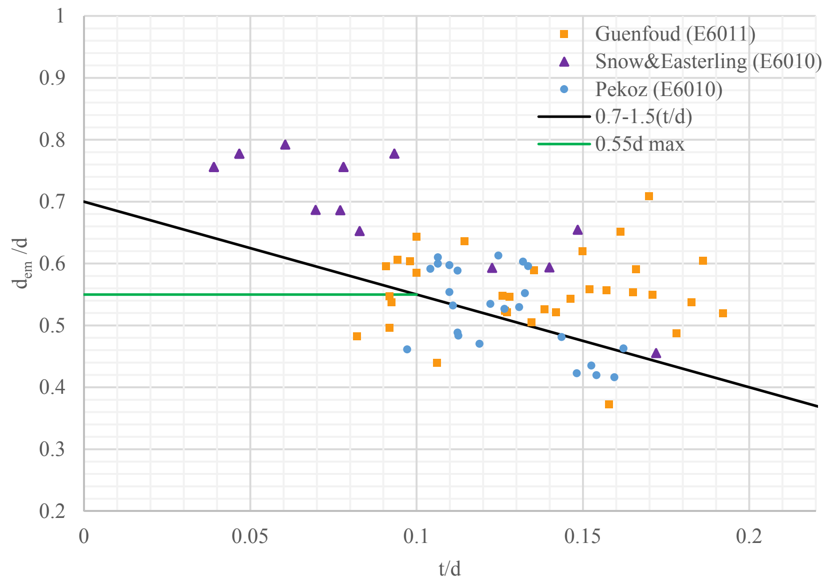


Figure 2: Shear Effective Weld Diameter Data**.**

Considering only the shear data as presented in Figure 2, the diagonal line, Equation E2.2.2.1-5 without the maximum limit, appears to represent the data well. But, by adding effective weld diameter data from Guenfoud's tension loaded samples it is clear Equation E2.2.2.1-5 under predicts weld diameters through thicker sheets as illustrated in Figure 3.

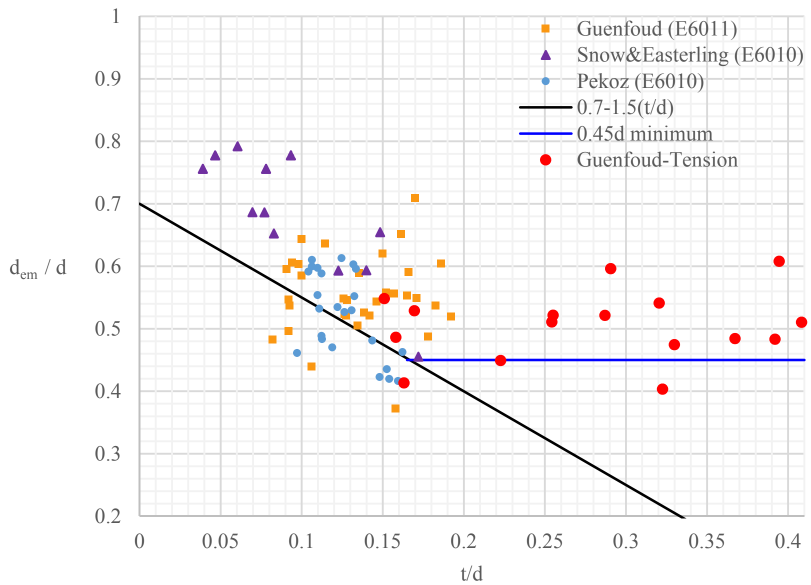


Figure 3: Shear and Tension Effect Weld Diameter Data.

This study recommends modifying Equation E2.2.2.1-5 by removing the upper limit of 0.55d and adding a lower limit of 0.45d in order to represent the entire arc spot weld database presented in Figure 3. This modification of Equation E2.2.2.1-5 is presented as Equation 1 below. Both Equation E2.2.2.1-5 and Equation 1 were used to analyze the performance of shear and tension weld failure equations. Equation 1 provided better results in both cases as detailed below.

Equation 1: $d_e$ = greater of $\left| \begin{array}{l} 0.7d - 1.5t \\ 0.45d \end{array} \right.$

**Shear: Weld Failure**

The 450 specimens within the data base were each categorized by failure mode. A total of 87 specimens were analyzed using AISI S100-12 Equation E2.2.2.1-1, the arc spot weld shear resistance equation. Resistance and safety factors were re-calibrated for each failure mode using AISI 2012 Section F1.1 procedures. The results for weld shear failure are listed in Table 1.

Comparing the effects of Equation E2.2.2.1-5 and Equation 1, both produced resistance and design factors that were very close that those currently listed in AISI S100-12. This indicates that the 0.55d maximum limit has little to no effect of the resistance calculation of welds in shear. The proposed 0.45d lower limit in

Equation 1 proves to be more influential in the resistance of welds in tension detailed below. Applying Equation 1, Equation E2.2.2.1-1 reached a measured to predicted strength ratio of 1.53 and a coefficient of variation equal to 0.326.

Table 1: E2.2.2.1-1, Weld Shear Failure Analysis Results.

| Design Factor | Existing AISI S100-12 | Recalibrated with E2.2.2.1-5 | Recalibrated with Equation 1 |
|---|---|---|---|
| $\phi$ (LRFD, $\beta_o = 3.5$) | 0.60 | 0.595 | 0.591 |
| $\Omega$ (ASD, $\beta_o = 3.5$) | 2.55 | 2.571 | 2.587 |
| $\phi$ (LSD, $\beta_o = 4.0$) | 0.50 | 0.450 | 0.448 |
| No. of Samples = 87 | | | |

*Note: $\beta_o$, is the target reliability index for the calculation of resistance and safety factors.

**Shear: Sheet Failure**

The shear resistance of connected steel sheets for an arc spot welded connections is calculated by AISI S100-12 Equations E2.2.2.1-2, E2.2.2-1-3 and E2.2.2.1-4. These equations predict at what shear load sheet tearing will occur. They are split by three different ranges of $d_a/t$, which is the ratio of average weld diameter to combined sheet thickness. Overall, this study found that these equations are satisfactory but their respective resistance and safety factors were conservative and can be improved.

A total of 104 specimens were categorized into Equation E2.2.2.1-2 $d_a/t$ ranges, meaning these specimens had smaller weld diameters and thicker combined sheets. This equation applied to majority of sheet shear failure specimens. The recalibrated resistance and safety factors improved as listed in Table 2 when considered with the expanded data base. The measured to predicted strength ratio calculated to 1.41 and the coefficient of variation calculated to 0.182 for Equation E2.2.2.1-2.

Table 2: E2.2.2.1-2, Sheet Shear Failure Analysis Results.

| Design Factor | Existing AISI S100-12 | Recalibrated |
|---|---|---|
| $\phi$ (LRFD, $\beta_o = 3.5$) | 0.70 | 0.787 |
| $\Omega$ (ASD, $\beta_o = 3.5$) | 2.20 | 1.943 |
| $\phi$ (LSD, $\beta_o = 4.0$) | 0.60 | 0.629 |
| No. of Samples = 104 | | |

AISI S100-12 Equation E2.2.2.1-3 applied to 23 specimens which met the middle $d_a/t$ range. The recalibrated resistance and safety factors significantly improved from those currently specified in AISI S100-12 as detailed in Table 3. Analysis of Equation E2.2.2.1-3 produced a measured to predicted strength ratio of 1.40 and a tight coefficient of variation of 0.122.

Table 3: E2.2.2.1-3, Sheet Shear Failure Analysis Results.

| Design Factor | Existing AISI S100-12 | Recalibrated |
|---|---|---|
| $\phi$ (LRFD, $\beta_o = 3.5$) | 0.55 | 0.865 |
| $\Omega$ (ASD, $\beta_o = 3.5$) | 2.80 | 1.770 |
| $\phi$ (LSD, $\beta_o = 4.0$) | 0.45 | 0.700 |
| No. of Samples = 23 | | |

No new data was available beyond Pekoz's 1979 report to analyze AISI S100-12 Equation E2.2.2.1-4, which was originally derived from the 1979 data. Equation E2.2.2.1-4 and its resistance and safety factors were recalibrated anyway with the five Pekoz specimens which applied to this high $d_a/t$ range. Table 4 show that the recalibrated factors match well with the existing AISI S100-12 factors. The measured to predicted strength ratio was 0.99 and the coefficient of variance was 0.167 for Equation E2.2.2.1-4 specimens.

Table 4: E2.2.2.1-4, Sheet Shear Failure Analysis Results.

| Design Factor | Existing AISI S100-12 | Recalibrated |
|---|---|---|
| $\phi$ (LRFD, $\beta_o = 3.5$) | 0.50 | 0.467 |
| $\Omega$ (ASD, $\beta_o = 3.5$) | 3.05 | 3.279 |
| $\phi$ (LSD, $\beta_o = 4.0$) | 0.40 | 0.364 |
| No. of Samples = 5 | | |

**Tension: Weld Failure**

AISI S100-12 Equation E2.2.3-1 calculates the resistance of arc spot welds under tension. This failure mode is more common with arc spot welds made in conjunction with weld washers. The weld washers reinforce the surrounding sheet thereby reducing chances of sheet tearing and directing failure through the weld. Recall this study focuses only on connections made without weld washers. Guenfoud was the only author able to produce tension weld failures without weld washers. He was able to penetrate through side lapped combined sheet thicknesses up to 0.23 inches (5.84mm) thick using an E6011 electrode. The resistance of the thick sheets were able to induce tension weld failures through 16 specimens.

Both Equation E2.2.2.1-5 and Equation 1 were used to assess Equation E2.2.3-1. As observed in Table 5, Equation E2.2.2.1-5 produced poor E2.2.3-1 strength predictions and a poor coefficient of variance equal to 1.43. Figure 3 highlights why. Equation E2.2.2.1-5 (diagonal line) severely under predicts the effective weld diameter of welds made through thicker sheets. By applying a lower limit of 0.45d as in Equation 1, the coefficient of variance sharpens to 0.362.

Even with the increase accuracy of Equation 1 over Equation E2.2.2.1-5, the average measured to predicted strength ratio was 0.62. The issue centered on the side lapped sheet configuration of these test samples common to practice. Loading side lapped sheets can cause stress concentrations at the weld perimeter, creating a peeling effect. As proposed by Guenfoud, a reduction coefficient, "r" equal to 0.50 is recommended for Equation E2.2.3-1. Table 6 illustrates the improvement of analysis results when applying Equation 1 and sequentially applying the reduction coefficient.

Table 5: E2.2.3-1, Weld Tension Failure Analysis Results.

| Design Factor | Existing AISI S100-12 | Recalibrated with Equation E2.2.2.1-5 and r = 0.50 | Recalibrated with Equation 1 and r = 0.50 |
|---|---|---|---|
| $\phi$ (LRFD, $\beta_o$ = 3.0) | 0.60 | 0.062 | 0.499 |
| $\Omega$ (ASD, $\beta_o$ = 3.0) | 2.50 | 24.677 | 3.066 |
| $\phi$ (LSD, $\beta_o$ = 3.5) | 0.50 | 0.026 | 0.368 |
| No. of Samples = 16 | | | |

*Note: $\beta_o$, is the target reliability index for the calculation of resistance and safety factors. AISI S100-12 specifies two options based on the application. Only results using the less conservative $\beta_o$ are presented in this paper.

Table 6: Improvement of E2.2.3-1 Performance Using Equation 1 and "r".

| | Recalibrated with Equation E2.2.1-5 | Recalibrated with Equation 1 | Recalibrated with Equation 1 and r = 0.50 |
|---|---|---|---|
| COV | 1.43 | 0.362 | 0.362 |
| Average ($P_t/P_n$) | 4.58 | 0.620 | 1.24 |
| $\phi$ (LRFD) | 0.062 | 0.249 | 0.499 |

*Note: $P_t$, is the measured failure load and $P_n$, is the predicted resistance of E2.2.3-1. COV stands for coefficient of variance.

**Tension Sheet Failure**

Tearing resistance of arc spot welded steel sheets subject to tensile loading is predicted by AISI S100-12 Equation E2.2.3-2. Three different sheet configurations common to practice can be subject to uplift forces and are each treated differently in the provisions when applying Equation E2.2.3-2. Resistance of interior arc spot welds are calculated from Equation E2.2.3-2 directly while the resistance of eccentric and side lap weld configurations are specified to be reduced by 50% and 30% respectively from that calculated by Equation E2.2.3-2.

A total 121 interior tension weld specimens analyzed proved Equation E2.2.3-2 to be an adequate strength estimate resulting in a coefficient of variance equal to 0.223 and a measured to predicted strength ratio equal to 1.27. The existing resistance and safety factors improved when recalibrated as observed in Table 7.

Table 7: E2.2.3-2, Interior Sheet Tension Failure Analysis Results.

| Design Factor | Existing AISI S100-12 | Recalibrated |
|---|---|---|
| $\phi$ (LRFD, $\beta_o$ = 3.0) | 0.60 | 0.767 |
| $\Omega$ (ASD, $\beta_o$ = 3.0) | 2.50 | 1.994 |
| $\phi$ (LSD, $\beta_o$ = 3.5) | 0.50 | 0.605 |
| No. of Samples = 121 | | |

The eccentric sheet specimens are those that had only one side of the connection loaded in tension, resulting in eccentric loading on the arc spot weld, simulating a perimeter roof weld. This study found that the currently specified 50% reduction (r) worked well and the recalibrated resistance and safety factors improved as shown in Table 8. From 40 specimens analyzed, the coefficient of variance was 0.278 and the measured to predicted strength ratio was 1.27.

Table 8: E2.2.3-2, Eccentric Sheet Tension Failure Analysis Results.

| Design Factor | Existing (r = 0.50) | Recalibrated (r = 0.50) |
|---|---|---|
| $\phi$ (LRFD, $\beta_o$ = 3.0) | 0.60 | 0.669 |
| $\Omega$ (ASD, $\beta_o$ = 3.0) | 2.50 | 2.287 |
| $\phi$ (LSD, $\beta_o$ = 3.5) | 0.50 | 0.516 |
| No. of Samples = 40 | | |

Side lap sheet configurations represent arc spot welds that are placed to connect adjacent sheet diaphragms. A total of 54 side lap specimens were available for analysis, consisting of both two sheet layers and four sheet layer configurations. AISI S100-12 specifies a 30% reduction (r equal to 0.70) for side lap samples. Alternative to a 30% reduction this study found that by taking the total combined sheet thickness as one half, the reduction was unnecessary. This idea stems from Laboube and Guenfoud's reports, who both observed that the failure of side lap specimens always occurred a mid-thickness, therefore only the sheet(s) making up the top lap where providing sheet tearing resistance.

Table 9 presents results when using half of the total combined sheet thickness and Table 10 shows results when using the full thickness. Using a 30% reduction (r equal to 0.70) and a full thickness, the resistance and safety factors recalibrate poorly compared to those specified in AISI S100-12, demonstrated in Table 10. While, using half of the combined sheet thickness, the resistance and safety factors improve, so much that a reduction is not necessary as illustrated in Table 9. When eliminating the reduction and using one half of the total sheet thickness, a coefficient of variance equal to 0.287 and a measured to predicted ratio equal to 1.46 were achieved.

Table 9: E2.2.3-2, Side Lap Sheet Tension Failure Analysis Results Using <u>Half</u> Combined Sheet Thickness.

| Design Factor | Existing (r = 0.70) | Recalibrated (r =0.70) | Recalibrated (r = 1.0) |
|---|---|---|---|
| $\phi$ (LRFD, $\beta_o = 3.0$) | 0.60 | 0.758 | 0.530 |
| $\Omega$ (ASD, $\beta_o = 3.0$) | 2.50 | 2.018 | 2.887 |
| $\phi$ (LSD, $\beta_o = 3.5$) | 0.50 | 0.583 | 0.408 |
| No. of Samples = 54 | | | |

Table 10: E2.2.3-2, Side Lap Sheet Tension Failure Analysis Results Using <u>Full</u> Combined Sheet Thickness.

| Design Factor | Existing (r = 0.70) | Recalibrated (r =0.70) | Recalibrated (r =0.50) |
|---|---|---|---|
| $\phi$ (LRFD, $\beta_o = 3.0$) | 0.60 | 0.406 | 0.569 |
| $\Omega$ (ASD, $\beta_o = 3.0$) | 2.50 | 3.768 | 2.689 |
| $\phi$ (LSD, $\beta_o = 3.5$) | 0.50 | 0.312 | 0.436 |
| No. of Samples = 54 | | | |

**Maximum Sheet Thickness**

AISI S100-12 specifies a maximum combined sheet thickness of 0.15 inches (3.81 mm) for arc spot welded connections. This limit is derived from the 1999 data base, where the thickest connections tested were below 0.15 inches (3.81 mm) thick. The expanded data base now includes arc spot welded connections with combined sheets up to 0.23 inches (5.84 mm) thick. As a case study, the sixteen specimens analyzed for Equation E2.2.3-1 were split into two groups; those above 0.15 inches (3.81 mm) and those below. The performance of both groups were compared to ensure the specimens above the current 0.15 inch (3.81 mm) limit performed equally was well as those below.

Six specimens were between 0.092 inches (2.34 mm) to 0.15 inches (3.81 mm) thick and ten specimens were between 0.15 inches (3.81 mm) and 0.23 inches (5.84 mm) thick. Applying Equation E2.2.3-1, and the recommendation of Equation 1 for effective weld diameter and a 50% reduction as detailed above, the results of both groups below and above the 0.15 inch (3.81 mm) limit are compared in Table 11. Specimens with combined sheets greater than 0.15 inches (3.81 mm) performed well and did not impact the results negatively when combined with specimens less than 0.15 inches (3.81 mm). The same is true for the other failure modes detailed here such as shear and tension sheet failure whose resistance and design factors improved despite encompassing analysis of specimens exceeding the 0.15 inch (3.81 mm) limit.

Table 11: Combined Sheet Thickness Comparison for Tension Weld Failures

| | $t \leq 0.15''$ | $0.15'' < t < 0.25''$ | Combined $t < 0.25''$ |
|---|---|---|---|
| Average ($P_t/P_n$) | 0.956 | 1.407 | 1.238 |
| COV | 0.212 | 0.339 | 0.362 |
| $\phi$ (LRFD, $\beta_o = 3.0$) | 0.497 | 0.564 | 0.499 |

**Conclusions**

The arc spot weld data base has significantly increased since the last comprehensive assessment performed in 1999 by the research additions of Peuler, LaBoube, Snow and Easterling, and Guenfoud. Combining new and old data, the applicability of the AISI S100-12 arc spot weld design Equations E2.2.2.1-1, E2.2.2.1-2, E2.2.2.1-3, E2.2.2.1-4, E2.2.2.1-5, E2.2.3-1 and E2.2.3-2 were reassessed.

The effective weld diameter calculation, Equation E2.2.2.1-5 was found to no longer best represent the expanded data base. It is recommended that the upper limit of 0.55d be removed and a lower limit of 0.45d be added. This modification was found to best represent the measured effective weld diameter data base and outperformed the original Equation E2.2.2.1-5 when applied to weld fracture Equations E2.2.2.1-1 and E2.2.3-1.

The maximum permitted combined sheet thickness of 0.15 inches (3.81 mm) specified in AISI S100-12 Section E2.2, no longer is applicable to the expanded arc spot weld data base which included specimens with combined thicknesses up to 0.23 inches (5.84mm). Thicker specimens up to 0.23 inches (5.84 mm) performed well in this study and it is recommended that AISI S100-12 raises the maximum permitted combined sheet thickness up to 0.25 inches (6.35 mm).

Shear sheet tearing Equations E2.2.2.1-2, E2.2.2.1-3, E2.2.2.1-4 performed well. The expanded data base included several new specimens in this category with the exception of Equation E2.2.2.1-4 of which no change is recommended here. The resistance and safety factors of Equations E2.2.2.1-2 and E2.2.2.1-3 improved with recalibration, and it is recommended that AISI increase these values as recommended in Table 12. The shear weld fracture Equation E2.2.2.1-1, performed well using the modified effective weld diameter calculation, Equation 1, and no change to its respective resistance and safety factors are recommended here. The recommendations to the shear provisions are summarized following.

Section E2.2 (current): "Arc spot welds shall not be made through steel where the thinnest sheet exceeds **0.25 in** (0.15 in) in thickness, nor through a combination of steel sheets having a total thickness over **0.25 in** (0.15 in)".

Modified E2.2.2.1-5 (Equation 1): $d_e$ = the greater of $\left| \begin{array}{l} 0.7d - 1.5t \\ 0.45d \end{array} \right.$

Table 12: Recommendation for AISI S100 Shear Provisions.

| **Arc Spot Weld – Shear *(Current S100-12 Italicized)*** | | | | | |
|---|---|---|---|---|---|
| **Limit State** | **Equ.** | **$d_a/t$** | **$\phi$ (LRFD)** | **$\Omega$ (ASD)** | **$\phi$ (LSD)** |
| Sheet Tearing | E2.2.2-2 | $d_a/t \leq 0.815\sqrt{(E/F_u)}$ | 0.80<br>*(0.70)* | 1.95<br>*(2.20)* | 0.65<br>*(0.60)* |
| | E2.2.2-3 | $0.815\sqrt{(E/F_u)} <$ $d_a/t$ $< 1.397\sqrt{(E/Fu)}$ | 0.85<br>*(0.55)* | 1.75<br>*(2.80)* | 0.70<br>*(0.45)* |
| | E2.2.2-4 | $1.397\sqrt{(E/F_u)} \leq d_a/t$ | 0.45<br>*(0.50)* | 3.25<br>*(3.05)* | 0.35<br>*(0.40)* |
| Weld Fracture | E2.2.2-1 | All | 0.60<br>*(0.60)* | 2.45<br>*(2.55)* | 0.50<br>*(0.50)* |

Tension weld fracture proved to be a rare failure mode without the use of weld washers. Equation E2.2.3-1 in conjunction with Equation E2.2.2.1-5, performed rather poorly for weld tension resistance prediction. This study recommends AISI modifies Equation E2.2.2.1-5 to Equation 1 to accurately predict the effective weld diameter of thicker specimens and that AISI applies a reduction factor "r" equal to 0.50 to account for non-uniform stress distributions in order to accurately predict weld tension resistance.

The tension sheet tearing Equation E2.2.3-2, performed well for interior and eccentric sheet configurations and their respective resistance and safety factors significantly improved. It is recommended that AISI specifies resistant and safety factors based on sheet configuration as listed in Table 13. After analysis of side-lap configurations, it is clear that the design thickness needs to be equal to one half of the total combined sheet thickness as this is where sheet failure occurred for all side-lap samples. By taking the design thickness as one half, the need for a 30% reduction as currently specified in AISI S100-12 is no longer necessary. The recommendations to the tension provisions are summarized following.

Modified E2.2.3-1: $P_n = (\underline{\mathbf{r}})\, \frac{\pi {d_e}^2}{4} F_{xx}$

Modified E2.2.3-2: $P_n = (\underline{\mathbf{r}})\, 0.8(F_u/F_y)^2 t d_a F_u$

Table 13-A: Recommendation for AISI S100 Tension Provisions.

| **Arc Spot Weld – Tension *(Current S100-12 Italicized)*** | | | | |
|---|---|---|---|---|
| **Limit State** | **Equ.** | **Sheet Configuration** | **Design Thickness - t** | **Reduction Factor - r** |
| Sheet Tearing | E2.2.3-2 | Single or Multiple Sheet | Total sheet(s) thickness | 1.0 |
| | | Side-lap | 50% of total sheet(s) thickness *(100%)* | 1.0 *(0.7)* |
| | | Edge (Eccentric Loading) | Total sheet(s) thickness | 0.5 |
| | | | | w/washers 1.0 |
| Weld Fracture | E2.2.3-1 | All | Total sheet(s) thickness | 0.5 *(1.0)* |

Table 13-B: Recommendation for AISI S100 Tension Provisions Continued.

| **Arc Spot Weld – Tension *(Current S100-12 Italicized)*** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Panel and Deck Applications** | | | **Other Applications** | | |
| **Equ.** | **Sheet Configuration** | **ϕ (LRFD)** | **Ω (ASD)** | **ϕ (LSD)** | **ϕ (LRFD)** | **Ω (ASD)** | **ϕ (LSD)** |
| E2.2.3-2 | Single or Multiple Sheet | 0.75 *(0.60)* | 2.00 *(2.50)* | 0.60 *(0.50)* | 0.65 *(0.50)* | 2.35 *(3.00)* | 0.50 *(0.40)* |
| | Side-lap | 0.55 *(0.60)* | 2.90 *(2.50)* | 0.40 *(0.50)* | 0.45 *(0.50)* | 3.50 *(3.00)* | 0.35 *(0.40)* |
| | Edge (Eccentric Loading) | 0.65 *(0.60)* | 2.30 *(2.50)* | 0.50 *(0.50)* | 0.55 *(0.50)* | 2.75 *(3.00)* | 0.45 *(0.40)* |
| E2.2.3-1 | All | 0.50 *(0.60)* | 3.05 *(2.50)* | 0.40 *(0.50)* | 0.40 *(0.50)* | 3.90 *(3.00)* | 0.30 *(0.40)* |

Further details concerning this study can be found in the full AISI 2016 report, “Resistance of Arc Spot Welds – Update to Provisions” authored by Blackburn and Sputo. This study was sponsored by the American Iron and Steel Institute and the Steel Deck Institute.

**Appendix. – References**

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**Appendix. – Notation**

$\beta_o$ = target reliability index
COV = coefficient of variance
d = visual weld diameter, located at the top sheet surface
$d_e$ = effective weld diameter, located at the failure plane
$\Omega$ = safety factor calculated for use in ASD
$\phi$ = resistance factor calculated for use in either LRFD or LSD
$P_n$ = predicted resistance of the respective AISI S100-12 strength equation
$P_t$ = measured resistance, failure load of the tested specimen
t = total combined sheet thickness
r = reduction coefficient