# ARC-PUDDLE WELDS
# AND WELD WASHERS
# FOR ATTACHMENTS IN STEEL DECK

Prepared By

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# THE USE OF ARC-PUDDLE WELDS AND WELD WASHERS FOR ATTACHMENTS IN STEEL DECK

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## Introduction

Steel deck panels may be installed using a wide variety of connections including powder driven fasteners, air driven fasteners, screws, or by various types of welding. The more common types of welded connections are either arc-spot welds or arc welds made through weld washers. Weld strength tests have been conducted at West Virginia University since the beginning of the Steel Deck Institute diaphragm test programs in 1968. The weld studies, described in this paper, have led to the following position adopted by the Steel Deck Institute.

> **Typical** *3/8” x 16 gage (0.060”)* **washers are not recommended with deck design thicknesses equal to or greater than** *0.028 inches.* **Weld washers are recommended for welding in deck panels thinner than** *0.028 inches*.

The direct arc-spot or “puddle” weld is started by striking an arc on the deck surface causing a hole to form in the deck. The weld operation then continues by depositing electrode material on the supporting element and allowing the “puddle” to engage the penetrated deck. It is essential that the finished weld be anchored into the supporting element and that the top puddle engage the penetrated unit on most of the weld perimeter. The complete welding process often is finished in five seconds or less and requires a welder who is qualified to make such welds.

Arc-puddle welding methods and operator qualifications are described in the American Welding Society Structural Welding Code for Sheet Steel, AWS D1.3. The welding process is different from welding in heavier steel elements in that the connected elements do not fall into the minimum thickness categories commonly required for welding in structural steel. The essential issue in forming a good weld rests in bringing all elements to fusion temperature at the same time, avoiding “burn-out” in the sheet, with adequate penetration into supporting elements, and with proper sheet engagement on the weld perimeter. A properly made weld should engage the connected sheet on at least *75%* of the weld perimeter.

Welding washers are small elements of sheet steel with a punched hole at their center and may be curved to fit into the valleys of deck panels. Refer to **Figure 2**. Washers may be of differing thickness and have different hole diameters or hole shapes. The most common types are about *0.06”* thick with holes of *3/8”* and may be designated as *3/8”* x *16 washers*. Weld washers are laid in position on the deck units, an arc is struck on the sheet inside the hole, and the operation continues usually until the hole is filled. The weld washer acts as a heat sink and retards burn-out in the sheet. The washer permits welds in thin units that might otherwise burn away from the welding operation faster than weld material can be deposited.

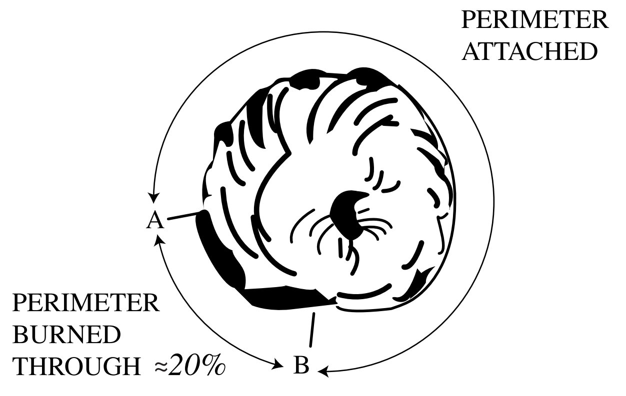


**FIGURE 1**

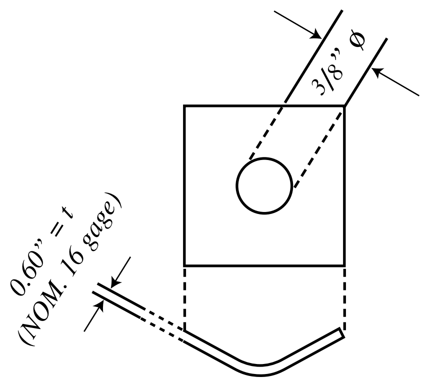


**FIGURE 2**

Quality welded connections require that the elements to be joined be in intimate contact for proper heat transfer; seldom can a gap between thin sheet elements be bridged with electrode material. The operator must select weld machine power settings sufficient to provide energy levels to raise substrate materials to fusion temperature while preserving the integrity of the hole formed in the steel panel. Welding quality will be more difficult to maintain in wet or cold conditions than in dryer warm conditions.

It is essential to understand the heat issue in welding. The weld washer draws some of the heat and may therefore greatly reduce the energy delivered to the substrate relative to that delivered in arc-spot welding without washers. With a five second welding time for example, it is possible to form a high quality weld through a weld washer into steel deck thicknesses between *0.015* and *0.028 inch* thicknesses. However, using the same washer type and the same welding rates with a thicker steel deck panel, may severly limit heat available for penetration into the substrate.

### Tests With Weld Washers.

An extensive program of weld shear strength tests was made at West Virginia University for the Steel Deck Institute and SDI member companies. These were the bases for weld strength recommendations in the SDI Diaphragm Design Manual where it was recommended that weld washers be used with sheet thinner than *0.028 inches*. Two different types of weld electrodes were used with welding energy levels being identified by electrode burn-off rates and the amount of weld rod used. Stop-watch welding times were recorded for each weld and burn-off rates established by measuring the amount of rod used.

**Table 1** contains results from tests with *3/8"* x *0.06"* thick washers used on the indicated steel thickness in the column, avg. $t$ (in). Welds through the steel sheets were made into A36 steel substrate of the inch thickness indicated in the "Plate" column.

In summarizing the results from **Tables 1 and 2**, direct comparisons can be made for the influence of E6013 vs. E7018 electrodes. In **Table 3**, the results are grouped according to sheet thickness only.

**Table 1. Weld Strength Summaries, E6013 - 3/8 *in.* Electrodes.**

| | | | | | Welding Averages | |
|---|---|---|---|---|---|---|
| No. Tests | Mark | Plate | Avg. $t$ (in.) | Avg. $Q_o$ (lbs) | Rate (in./sec.) | Time (sec.) |
| 1 | E | 3/16 | 0.0140 | 1380 | 0.257 | 3.4 |
| 1 | E | 1/4 | 0.0159 | 1116 | 0.257 | 3.6 |
| 5 | E | 1/4 | 0.0148 | 1169 | 0.179 | 4.5 |
| 2 | F | 3/16 | 0.0158 | 1280 | 0.257 | 4.0 |
| 2 | F | 3/16 | 0.0161 | 945 | 0.140 | 6.2 |
| 3 | F | 1/4 | 0.0158 | 1190 | 0.140 | 4.6 |
| 4 | A | 3/16 | 0.0140 | 1132 | 0.193 | 4.3 |
| 2 | A | 1/4 | 0.0140 | 1002 | 0.257 | 3.4 |
| 1 | A | 5/16 | 0.0140 | 1036 | 0.193 | 4.8 |
| 5 | B | 1/4 | 0.0183 | 1120 | 0.228 | 3.3 |
| 2 | B | 1/4 | 0.0176 | 1704 | 0.257 | 3.5 |
| 4 | C | 1/4 | 0.0248 | 1762 | 0.236 | 3.4 |
| 1 | C | 5/16 | 0.0252 | 2330 | 0.236 | 3.7 |
| 2 | C | 5/16 | 0.0250 | 2468 | 0.275 | 3.5 |
| 3 | D | 1/4 | 0.0295 | 2529 | 0.249 | 3.6 |
| 5 | D | 5/16 | 0.0294 | 2773 | 0.221 | 4.9 |

43 tests total

See footnotes with **Table 2**.

**Table 2. Weld Strength Summaries, E7018 - 1/8 *in.***

| | | | | | Welding Averages | |
|---|---|---|---|---|---|---|
| No. Tests | Mark | Plate | Avg. $t$ (in.) | Avg. $Q_o$ (lbs) | Rate (in./sec.) | Time (sec.) |
| 6 | A | 3/16 | 0.0142 | 1168 | 0.177 | 5.5 |
| 1 | A | 1/4 | 0.0145 | 1280 | 0.177 | 4.6 |
| 5 | E | 1/4 | 0.0148 | 1121 | 0.213 | 3.4 |
| 2 | E | 1/4 | 0.0146 | 1384 | 0.219 | 3.5 |
| 5 | F | 1/4 | 0.0160 | 1098 | 0.215 | 3.1 |
| 2 | F | 1/4 | 0.0160 | 1418 | 0.219 | 3.6 |
| 7 | B | 1/4 | 0.0182 | 1788 | 0.236 | 3.6 |
| 7 | C | 5/16 | 0.0248 | 2538 | 0.206 | 4.0 |
| 7 | D | 1/4 | 0.0306 | 3122 | 0.203 | 4.5 |

35 tests total

$Q_o$ = *tested shear strength, lbs./weld.*
$t$ = *average base metal thickness, in.*

Mark A: Black coil marked A625 with $F_y = 116$ *ksi.*
Mark B: Uncoated A611E, $F_y = 111$ *ksi* & $F_u = 115$ *ksi.*
Mark C: Galv. A446E, $F_y = 93$ *ksi* & $F_u = 98$ *ksi*
Mark D: Uncoated A366
Mark E: Uncoated A625, $F_y = 121$ *ksi.*
Mark F: Galv. A446 E, $F_y = 96$ *ksi* & $F_u = 97$ *ksi.*

**Table 3. Comparisons for Electrode Type.**

| | E6013 | | E7018 | | Strength | Volume* |
|---|---|---|---|---|---|---|
| **Mark** | **Tests** | **Avg. $Q_o$** | **Tests** | **Avg. $Q_o$** | **E70/E60** | **E70/E60** |
| E (28 ga.) | 7 | 1192 | 7 | 1196 | 1.00 | 0.88 |
| F (28 ga.) | 7 | 1146 | 7 | 1189 | 1.04 | 0.86 |
| A (28 ga.) | 7 | 1081 | 7 | 1184 | 1.10 | 1.11 |
| B (26 ga.) | 7 | 1286 | 7 | 1788 | 1.39 | 1.07 |
| C (24 ga.) | 7 | 2050 | 7 | 2583 | 1.26 | 0.96 |
| C (22 ga.) | 8 | 2682 | 7 | 3122 | 1.16 | 0.91 |

* Volume: Avg. burn-off rate x welding time.

The next-to-last column indicates that, under similar welding conditions, the E70 welds were stronger than the E60 welds even though weld strength was controlled by bearing in the sheet rather than shearing across the weld stem. During the welding process, it was noted that the E70 electrodes would "wet" the perimeter of the washer more smoothly and that the finished weld appearance was more even. It is apparent that the more even electrode deposition characteristic was more important than weld rod strength.

## Strength and Stiffness Formulations.

An evaluation of the above data for welds with $3/8"$ x $0.06"$ washers leads to the following formulas for individual weld strength under shear loads and for shear flexibility.

$$Q_f = 99t\,(0.5 + 0.3\,F_{xx}\,t),\ kips \qquad (1)$$

$$S_f = 1.15 \times 10^{-3}/\sqrt{t},\ inch/kip \qquad (2)$$

where $t$ = *base metal thickness, inches.*

$F_{xx}$ = *electrode strength, ksi*

**Table 4. Tested to Theoretical Strength Comparisons.**

| | E6013 | | | | E7018 | | | |
|---|---|---|---|---|---|---|---|---|
| **Mark** | **No.** | **Avg. $Q_o$** | **$Q_f$** | **$Q_o/Q_f$** | **No.** | **Avg. $Q_o$** | **$Q_f$** | **$Q_o/Q_f$** |
| E (28 ga.) | 7 | 1192 | 1123 | 1.06 | 7 | 1196 | 1188 | 1.01 |
| F (28 ga.) | 7 | 1146 | 1238 | 0.93 | 7 | 1189 | 1313 | 0.91 |
| A (28 ga.) | 7 | 1081 | 1042 | 1.04 | 7 | 1184 | 1101 | 1.08 |
| B (26 ga.) | 7 | 1286 | 1480 | 0.87 | 7 | 1788 | 1577 | 1.13 |
| C (24 ga.) | 7 | 2050 | 2237 | 0.92 | 7 | 2583 | 2522 | 1.02 |
| C (22 ga.) | 8 | 2682 | 2996 | 0.90 | 7 | 3122 | 3252 | 0.96 |

$Q_o$ = *tested shear strength, lbs./weld.*
$Q_f$ = *theoretical shear strength, lbs./weld.*

Equation 1 does not contain a specific term for ultimate strength, $F_u$, of the deck sheet material and $F_u$ variations may not be of paramount importance. The weld washer focuses heat around the weld, raises the sheet to fairly controlled "red-hot" temperatures, leading to significant annealing relief of any "rolled-in" stresses from cold working. This may leave the adjacent sheet material with an ultimate strength, $F_u$, well below full-hard strength levels for example.

The comparisons in **Table 4** are for weld washers with *3/8"* holes. All welds were made with fairly consistent burn-off rates and welding times. The E70 series performed a bit better than the E60 series. Only with welds in the *22 gage* material did any shear failure across the weld develop; all other welds failed in bearing on the steel sheet thickness.

### Other Weld Washer Studies.

Loadmaster Roof Deck Systems, Inc. of Dallas, Texas initiated a weld study at West Virginia University in 1984 involving a variety of weld washer types and thicknesses. That study included weld washers in three thicknesses, *0.061*, *0.089*, and *0.115 inches*, and having either round or slotted holes. Round hole sizes were *3/8*, *7/16*, and *1/2 inches*. Slotted washers had oblong-like openings *1/4* by *1 inch*.

The Loadmaster washers were tested on deck sheets with thicknesses of *0.0144*, *0.0194*, *0.0210*, *0.0243*, *0.026*, and *0.0302 inches*. The study was directed toward optimizing weld strength by changing weld washer thickness, opening shape, and welding rates. Indeed it is possible to make "super strength" welds. With a fixed burn-off rate, a change from a *3/8"* to a *1/2"* weld washer will require increased welding time to deposit the volume of weld material, and this extra time will allow deeper heat penetration into the substrate. The time will increase roughly with the square of the washer diameter, here about *55%*, allowing the weld to "grow" more evenly into the washer with a greater effective diameter. The visible weld diameter almost always is greater that the washer hole diameter. For this particular case in the Loadmaster study, it was found that the 55% increase in welding time would lead only to a *20%* increase in weld strength.

> **Weld washer strength increases in a near-linear fashion with increases in hole diameters when using a given washer thickness. However, the electrode material required and the welding time needed vary more nearly with the square of the hole diameter.**

The efficiency study included balancing strength changes against the welding material used and led to the conclusion that the most efficient washers were *3/8"* x *0.06 inches*. When higher weld strengths are required, the *1"* x *1/4"* slotted washers were found to be the next most efficient washers.

The direction of the study was toward determining relative strength characteristics of welds with washers of several different thicknesses and opening shapes. Focusing only on those with *3/8"* holes, the isssue was, "What weld times and burn-off rates would be required to meet the expectations of Equation 1?" Slightly larger diameter E6013-5/32" electordes were used for the results in following table.

**Table 5. Weld Strength Summaries, E6013 - *5/32 in.***

| | | | | Averages | |
|---|---|---|---|---|---|
| No. Tests | Average values | | | Rate | Time |
| | $f_y$ | $t$ (in.) | $Q_o$ (lbs) | (in./sec.) | (sec.) |
| 3 | 100.7 | 0.0144 | 1000 | 0.163 | 6.42 |
| 2* | 100.7 | 0.0144 | 900 | 0.177 | 7.25 |
| 3 | 105.0 | 0.0194 | 1460 | 0.172 | 7.25 |
| 4* | 105.0 | 0.0194 | 1673 | 0.171 | 8.06 |
| 2 | 110.6 | 0.0243 | 2250 | 0.156 | 7.63 |
| 1* | 110.6 | 0.0243 | 1700 | 0.156 | 7.75 |
| 2 | 104.8 | 0.0302 | 3450 | 0.172 | 9.75 |
| 2* | 104.0 | 0.0302 | 3150 | 0.172 | 9.38 |

* *0.089”* thick washers, all others were *0.061”*

The last 2 entries in first-listed **Table 1** represent eight welds into *0.0295”* average steel thickness. Using weighted averages per weld, the burn-off rate is *0.231 in./sec.*, the welding time is *4.41 seconds*, and the strength is *2618 lbs*. With the *2%* increase in steel thicknesses to *0.0302”*, the last four weld entries in **Table 5** show average strengths of *3300 lbs*. per weld, *26%* higher than the **Table 1** values. This increase is almost totally related to the better weld quality attained by lowering burn-off rates and using longer welding times.

As indicated earlier, the Loadmaster weld study program demonstrated that it is possible increase weld strength by increasing the washer hole diameter, or by changing to slotted openings, or by increasing the welding time.

## Arc-Spot Welds.

The 1981 Edition of the SDI Diaphragm Design Manual presented the results from a series of weld shear tests which were used as the basis for the LRFD studies leading to the recommended shear design equations and load factors for diaphragms. The same basic formulations were continued in the 1987 SDI Diaphragm Design Manual and the current 2004 edition. The following formulas for shear strength and stiffness are from Sections 4.2.1 and 4.4 of the 2004 edition.

$$Q_f = 2.2t\, F_u (d - t) \qquad (3)$$

$$S_f = 1.15 \times 10^{-3}/\sqrt{t} \qquad (4)$$

where the terms are defined following Eqn. 2. For welded diaphragms, the basic SDI design tables presume the steel deck to be made of ASTM A653 steel with a *33 ksi* yield and $F_u = 45$ *ksi*. Substituting these into leads to a minimum weld strength,

$$Q_f = 99t\,(0.625 - t) \qquad (5)$$

for welds with a visible external diameter of *5/8 inches*.

The ultimate steel strength, $F_u$, does not appear directly in Eq. 1 for welds in washers; this equation was written for $F_u = 45\ ksi$. However, full-hard material was tested in the weld studies. For ASTM A653 and A1008 full hard steels, design strength values are set at $F_u = 82\ ksi$. Inserting $F_u = 82\ ksi$ into the arc spot weld Eq. 3, direct comparisons can be made between the two equations. For nominal 5/8" arc-spot welds, Equation 3 becomes

$$Q_f = 2.2\ (82)\ t\ (d - t) = 180t\ (0.625 - t) \qquad (6)$$

With E60 electrodes and using selected steel thicknesses, theoretical weld strengths can be compared as in **Table 6**.

**Table 6. 5/8" Arc-Spot Weld and 3/8" Weld Washer Equation Comparisons.**

| Thickness (in.) | $Q_{fs}$ 5/8" Spot | $Q_{fw}$ 3/8" Wash. | $Q_{fs}/Q_{fw}$ |
|---|---|---|---|
| 0.0150 | 1647 lbs | 1144 lbs | 1.44 |
| 0.0180 | 1967 lbs | 1468 lbs | 1.34 |
| 0.0240 | 2596 lbs | 2214 lbs | 1.17 |
| 0.0295 | 3162 lbs | 3011 lbs | 1.05 |
| 0.0358 | 3797 lbs | 4056 lbs | 0.94 |
| 0.0475 | 4938 lbs | 6372 lbs | 0.76 |
|  |  |  | **Average = 1.15** |

The last column of Table 6 implies that arc spot welds exhibit strengths about 15% greater than would welds having 3/8" x 16 gage washers. That conclusion is faulty since sheet stability around the weld is an issue especially in thin steel sheets.

Arc-spot welds in thin sheets, even if they can be well made, leave the sheet material in a distorted condition around the weld. With shear loading and the welds bearing on the sheet, distortion and buckling develops early and usually results in material pile-up against the weld with subsequent tearing in the sheet. The same type of thin sheet would be restrained from buckling by a weld washer. It would behave much as if the sheet were held in place with a bolt and washer.

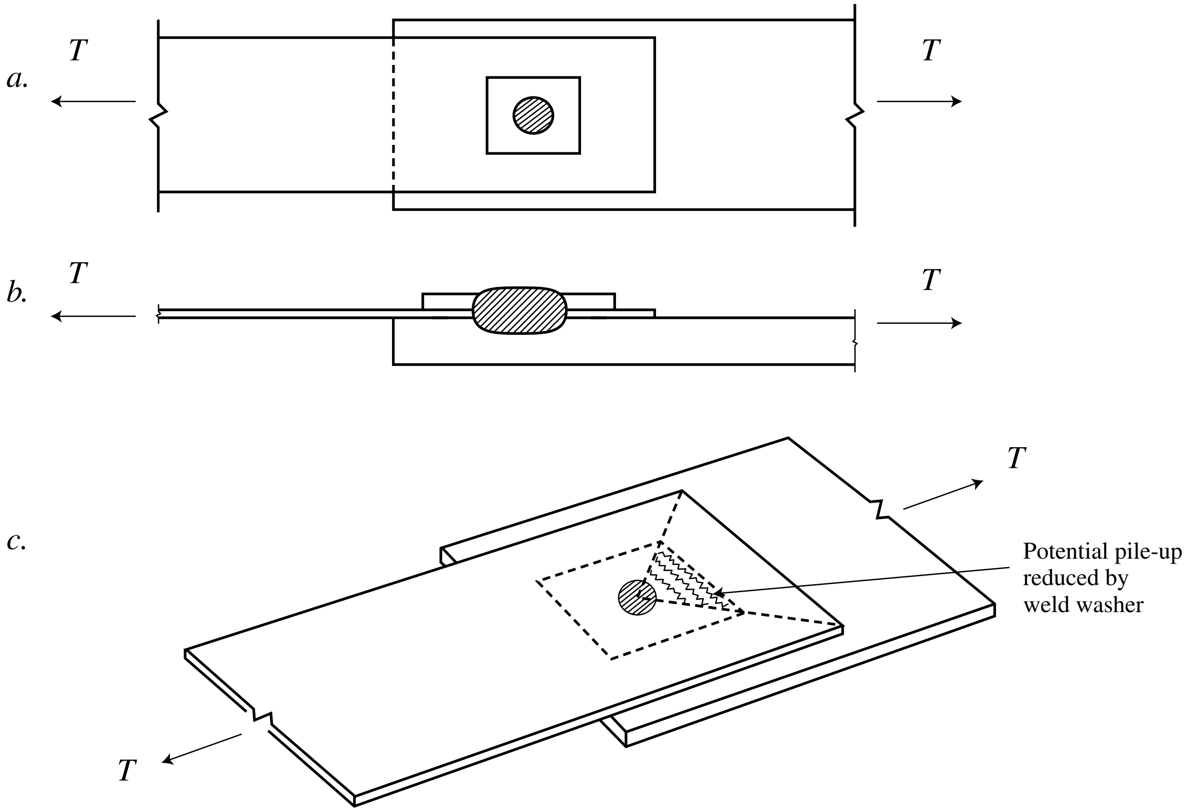
At the other extreme with thicker sheets, the sheet is not so sensitive to distortion with arc-spot welding nor to tearing in the sheet as the weld is loaded. Using a weld washer then could add little to strength since it is not limited by sheet stability. *However, the weld washer does demand heat and removes part of the energy that would be available for fusion into the substrate. With fixed welding programs and welding times on the order of 5 seconds per weld, it is not uncommon for the washer to reduce or virtually eliminate fusion to the substrate when welds are made through sheets of Type 22 (0.0295") or thicker.*

The Steel Deck Institute considered the above conditions when establishing its recommendations for weld washer use. The study was focused on the usual construction conditions of “short duration welding,” commonly less than five seconds per weld. The SDI recognizes that the design engineer may require stronger welds using larger diameter washers and longer welding times. Such connections can be used if they are evaluated following standard procedures such as those in Section 4.8 of the SDI Diaphragm Design Manual.

Under typical welding conditions, the Steel Deck Institute test programs support the adopted recommendation:

> **Typical *3/8” x 16 gage (0.060”)* washers are not recommended with deck design thicknesses equal to or greater than *0.028 inches*. Weld washers are recommended for welding in deck panels thinner than *0.028 inches*.**

Illustration of Weld Washer under Shear Load, T



*a.* Plan view with weld washer.
*b.* Section view indicating weld stem.
*c.* Isometric view indicating potential panel distortion under shear load, *T*.

**FIGURE 3**

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