BONAL TECHNOLOGIES INC
SUBSIDIARY OF BONAL INTERNATIONAL, INC.

January 25, 2007

Bonal Technologies, Inc. contracted Applications Technologies Company, LLC of Columbus, Ohio, a weld testing and consulting company, to design a test that would demonstrate our patented “Pulse Puddle Arc Welding” (PPAW)® technology’s ability to control welding distortion and the ability to weld faster while maintaining a good or better weld joint.

The results show that using PPAW technology, a welder can expect to have up to 95% less distortion compared to “normal” welding procedures. If the welder increases their welding speed 25% they can still achieve up to a 66% reduction in distortion.

If all arc welding was done using PPAW at welding speeds that are 25% faster, the shortage of welders would be a non-issue.

Test Run Number	Travel Speed	Angular Distortion	PPAW	% Distortion
11	20 ipm	2.289	No	100
4	20 ipm	0.122	Yes	5
3	25 ipm	0.774	Yes	33

Bonal Technologies, Inc. 1300 North Campbell Road • Royal Oak, MI 48067 • USA
Voice: (248) 582-0900 or 800 Metal-29 • Fax: (248) 582-0901 • info@bonal.com • www.bonal.com

Results of Distortion Comparison Trials on Steel –
With and Without *Pulse Puddle Arc Welding*®

Introduction

Applications Technologies Company LLC (ATC) was contracted by Bonal Technologies, Inc. (BTI) to independently investigate the use of their Pulse Puddle Arc Welding® (PPAW) Sub-harmonic technology in terms of its ability to reduce distortion when welding structural components. Initially, some very simple laboratory tests were conducted to both optimize the PPAW process as well as compare distortion tendencies in sample joints when welding with and without PPAW. This report describes the test program as well as the test results.

Test Program

To determine what PPAW settings produced the best results, the test trials to be performed were established using a Design of Experiments (DOE) approach. Using this method, a minimum number of tests can be conducted to determine the relationship among multiple variables. Those variables selected to change included: frequency, eccentric load, and travel speed. However, to produce consistent weld sizes at the various travel speeds, the wire feed speed was adjusted to result in a constant ratio of travel speed versus wire feed speed. The test matrix appears below:

RunOrder	CenterPt	Frequency	Eccentric Load	Travel Speed	Distortion Angle	Linear Displacement (in)
1	0	48.6	3	20	0.419	0.022
2	1	46.2	2	15	0.449	0.240
3	1	46.2	2	25	0.774	0.040
4	0	48.6	3	20	0.112	0.006
5	1	51	4	25	1.298	0.068
6	1	51	4	15	2.326	0.122
7	1	46.2	4	15	2.572	0.135
8	1	51	2	25	2.609	0.137
9	1	46.2	4	25	2.180	0.114
10		PPAW off	PPAW off	15	3.331	0.174
11		PPAW off	PPAW off	20	2.289	0.120
12		PPAW off	PPAW off	25	2.401	0.126

As can be seen from this table, three different values were used for the three variables, as described below. The mid-value sub-harmonic frequency value of 48.6 Hz was selected based on recommendations by Bonal's literature and technical staff. The mid range frequency was selected using an eccentric load of 3 and 10% of the harmonic peak as shown in Figure 1. Then, frequency values were selected slightly above (51Hz) and below (46.2 Hz) this mid-value. Similarly, the recommended eccentric load for this application was 3. Using this as a mid-value, lower and higher values used were 2 and 4, respectively. Then, three different travel speeds were selected that provided acceptable weld bead profile and weld size. These values, 15, 20 and 25 in/min, were considered typical for welded fabrication of these thicknesses. As noted above, the wire feed speeds were adjusted such that an approximately consistent ratio of travel speed to wire feed speed was maintained to allow for creation of fillet welds of approximately the same size. A mechanized welding cell was used to improve test consistency and repeatability. Figure 2 shows this test setup.

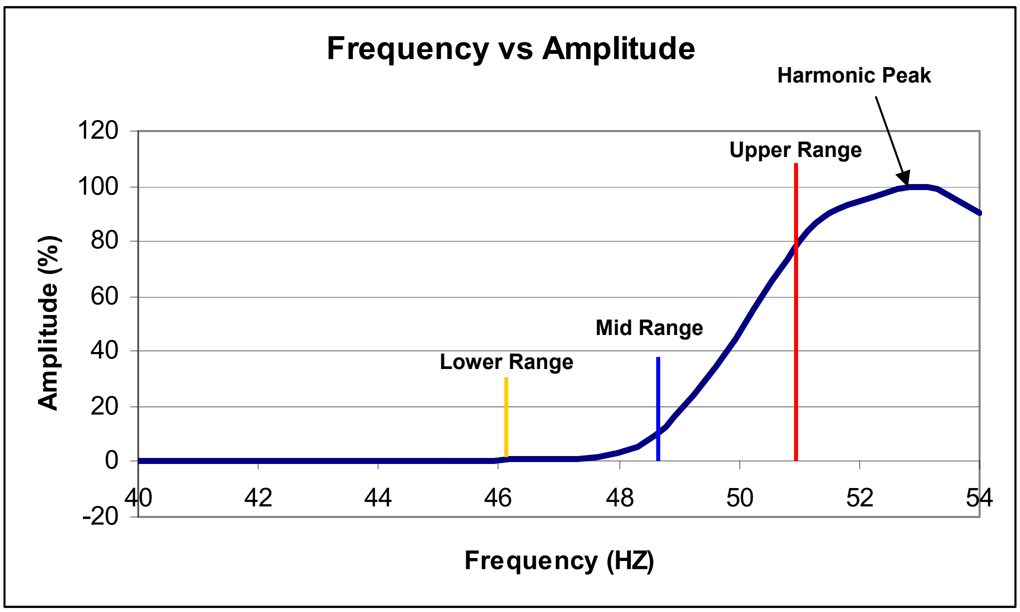

Figure 1. Selection of Frequency using Harmonic Peak

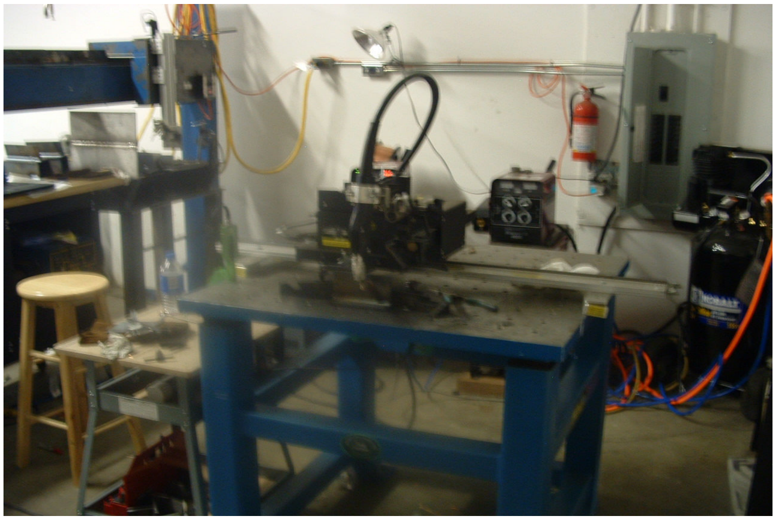

Figure 2. Overall view of test setup

As can be seen, the Bug-O track was placed on the welding table, along with the test pieces. Weld trials were conducted using a Power Maser 500P by Thermal Arc using ER70S-6 filler metal and 98%Ar/2%O_2. The test plates consisted of a ¼-in 1020 steel vertical plate in which the mating edge was machined to maintain consistence fitup. The bottom plate was 3/8-in 1020 steel. thick to maintain rigidity and provide a worse case for angular distortion between the vertical plate and the bottom plate. These T-joints were then fit and tacked at the ends in an identical manner and then clamped such that the bottom plate was in intimate contact with the table and the stem of the tee was free to move. The image below shows a closeup of the welding gun with respect to the T-joint.

Figure 3. Closeup of Overall view of test setup

The test matrix was executed and all of the welds were considered visually acceptable. The welding parameters used resulted in a spray transfer deposit, with excellent appearance and freedom from undercutting at the upper weld toe. Once welds were produced and allowed to cool, a section was cut from the center of each sample. These samples were then carefully measured to determine the amount of angular distortion produced during each trial.

Test Results

It was noted above that the purpose of these trials was to both verify which settings of the Bonal system were optimum as well as compare the amount of distortion in the test pieces with and without PPAW. Results of these studies appear below

Process Optimization

The DOE approach allows for the creation of both Main Effects and Interaction plots which use the amounts of measured distortion as the means of comparing the results. These two families of plots appear as Figures 4 and 5.

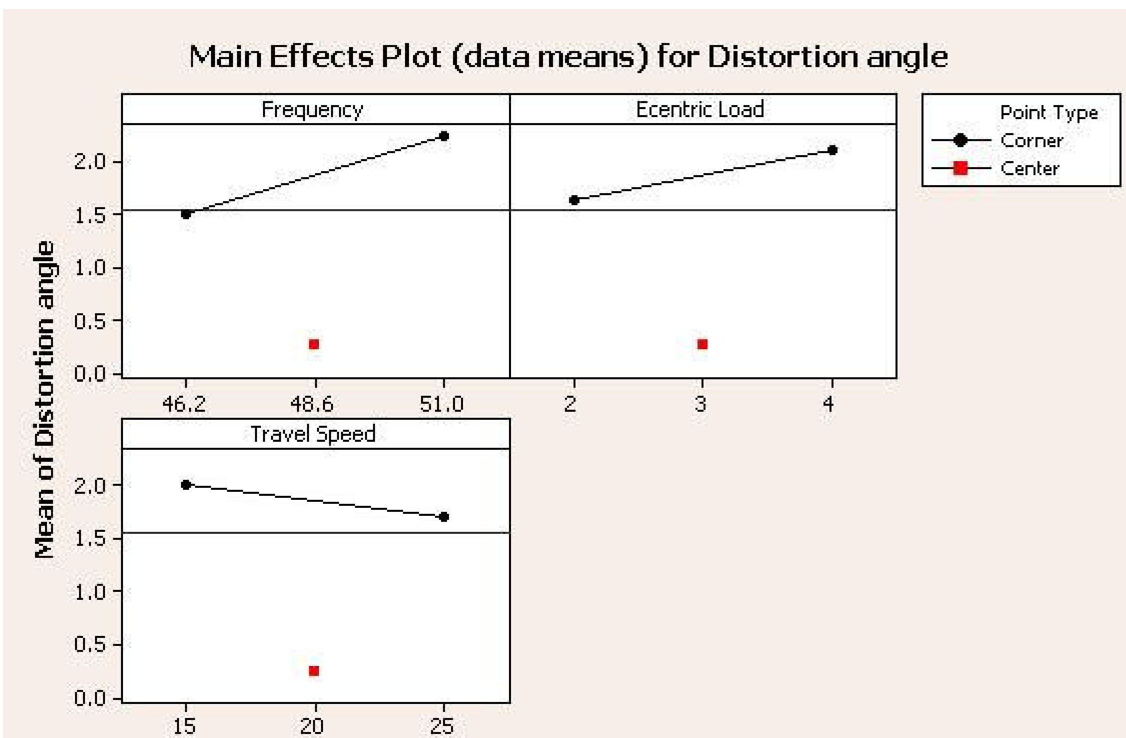

Figure 4. Main effects plot (data means) for distortion angle

The purpose of a main effects assessment is to determine how each variable independently influences the measured response. The measured response for this work was distortion. Therefore the objective of the main effects evaluation was to determine how frequency, eccentric load, and travel speed influence the amount of distortion caused during welding. The evaluation is conducted by statistically evaluating how changing one of the variable manipulates the amount of distortion. The above charts can be interpreted by using the slope of the response lines to determine the severity that altering the individual variable has on distortion, e.g. the steeper the slope, the more influence the variable has on the measured response.

From the Main Effects chart it is evident that as frequency and eccentric load increase the amount of measured distortion increases. The results also indicate that a faster travel speed reduces distortion. However, the Main Effects plot does not take into account interactions between variables. This is the purpose of the Interaction plots shown in Figure 5.

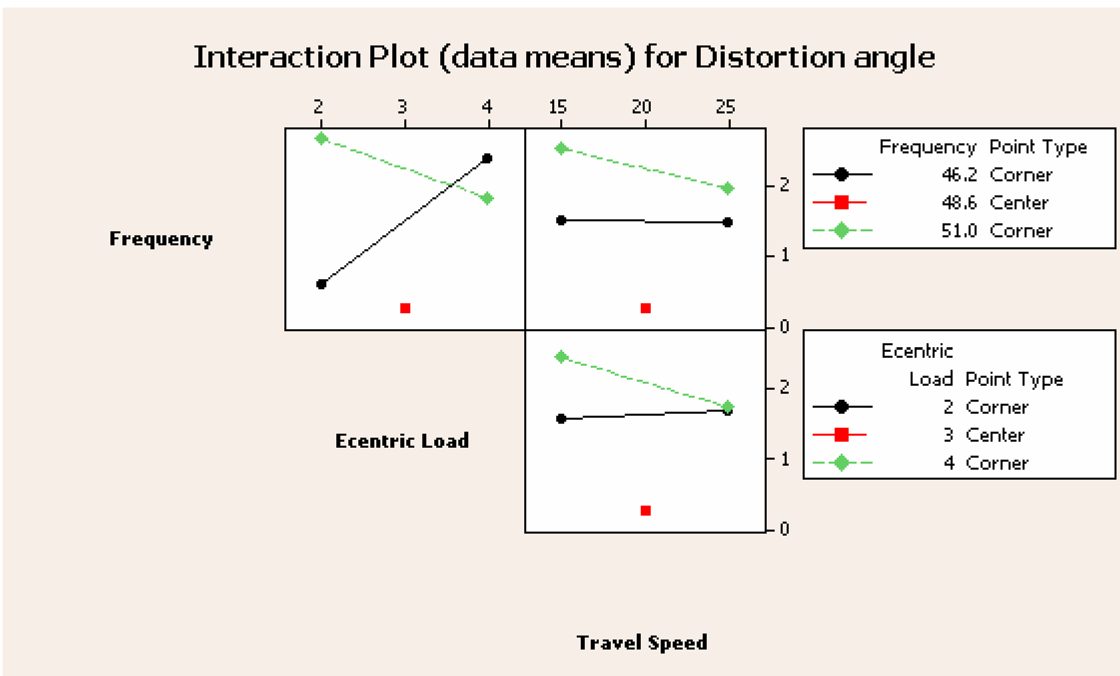

Figure 5. Interaction plots (data means) for distortion angle

Interaction plots are similar to Main Effects Plots in that, the greater the slope of the line the greater the interaction. They show that of the three variables, frequency and eccentric load have the greatest interaction effect on the amount of distortion expected. It further indicates that, at the lowest frequency (46.2), the best results will be attained with a low eccentric load (4). Conversely, a high frequency (51) and a high eccentric load (4) will produce the least distortion.

The results indicate that distortion response is unaffected by a low frequency at all travel speeds. However, the results indicated that an increased frequency can be beneficial at lower travel speeds. The Interaction plot also suggests that a low eccentric load has the same effect regardless of the travel speed but that an increased eccentric load causes more distortion at lower travel speeds.

The results of the DOE suggest that using the mid-range variables provide minimal distortion. This conclusion is based on the measured results of the DOE and conclusions derived from the Main Effects and Interaction plots indicating that the center points provided the least distortion. These results have a statistical correlation of 99.5%.

<u>Comparison of PPAW vs. non-PPAW</u>

The primary purpose of this study was to demonstrate that the Pulse Puddle Arc Welding® technology provides benefit in terms of reducing the amount of distortion occurring as the result of welding. In this study, nine trials were run using PPAW at various settings. Then, three additional trials (at three different travel speeds) were run with out the use of PPAW. Welds were cross section in the middle of the weld and distortion measured as a function of angular and linear distortion. Figure 6 illustrates how angular and linear distortion was evaluated. The results of all twelve tests are plotted in Figure 7 and 8, with trials shown as a function of the amount of measured angular distortion and linear distortion.

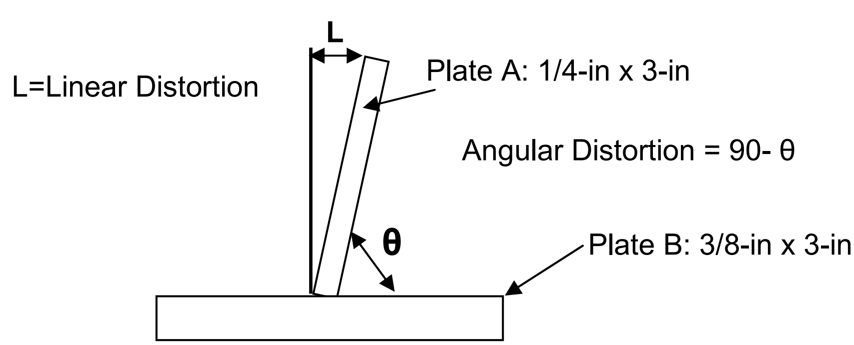

Figure 6. Illustration of Angular Distortion

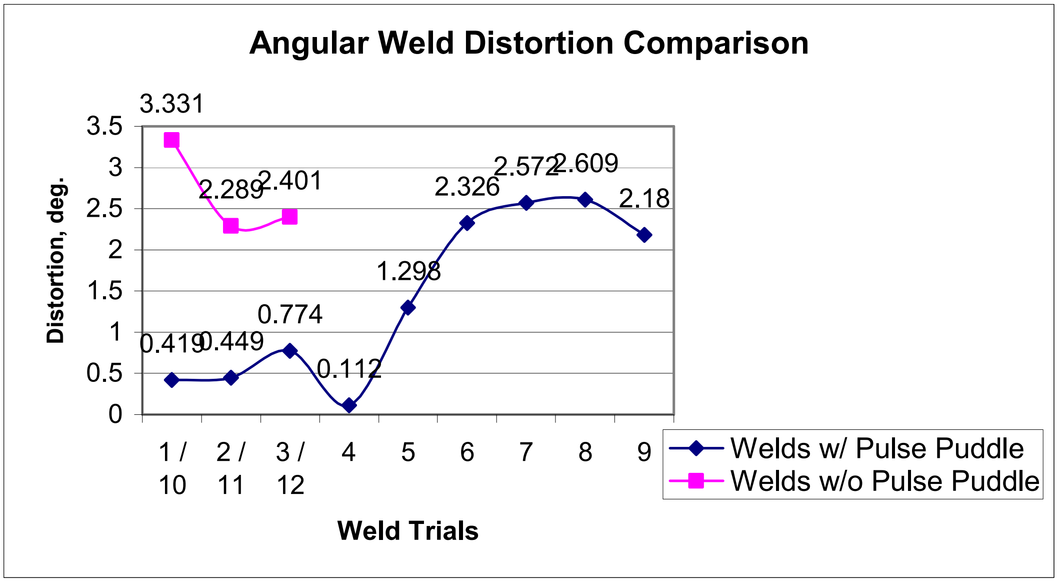

Figure 7. **Angular distortion in weld trials with and without PPAW**

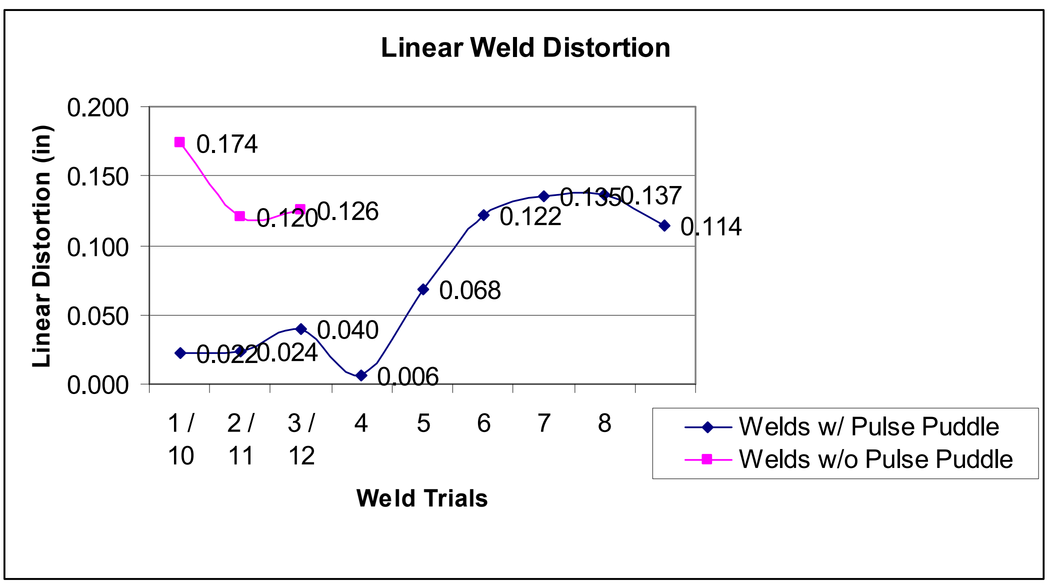

Figure 8. **Linear distortion in Weld Trials with and without PPAW**

While none of the samples exhibited significant amounts of distortion, there was a clear separation between those welded with optimal sub-harmonic vibratory PPAW parameters versus those welded without vibratory excitation. Upon initial observation, it appears that some of the PPAW values are greater than those without PPAW; however, to draw a correct comparison, one must break the data into like travel speed groups.

For example, trial #10 (3.331°) was run at 15 in/min, as were trials #2 (0.449°), #6 (2.326°), and #7 (2.572°). Trial #11 (2.289°) was run at 20 in/min, as were trials #1 (0.419°) and #4 (0.112°). Finally, trial #12 (2.401°) was run at 25 in/min, as were trials #3 (0.774°), #5 (1.298°), #8 (2.609°), and #9 (2.18°).

The lowest amount of distortion was noted in trial #4, in which only 0.112° of distortion was measured. In practical terms, this equates to essentially no distortion, as it can barely be measured. This trial was welded using a frequency of 48.6, an eccentric load of 3, and a travel speed of 20 in/min. The values of frequency and eccentric load were those recommended by Bonal literature for this application, so this provides additional verification that the methods prescribed by Bonal are valid and can lead to distortion mitigation.

Conclusions and Recommendations

The optimization study verified that Bonal's recommended settings provided the least amount of angular distortion. It further indicated that frequency appears to have the greatest affect on the resulting amount of distortion. Similarly, the interaction between frequency and eccentric load is the most significant interaction effect.

In terms of a comparison of the amount of distortion with or without PPAW, there is a clear indication that PPAW, when properly applied, will produce a reduced amount of distortion. Results indicate that optimal PPAW can reduce distortion as much as 95% compared to welds conducted without the use of PPAW.