# Widening the Welding Lobe of Advanced High Strength Steels in the Resistance Spot Welding Process

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## Abstract

The intention of this project was to examine the resistance spot welding (RSW) process for advanced high strength steels (AHSS) and to explore ways of increasing the width of the welding lobe of acceptable parameters. In this way, it was hoped that more robust process parameters could be developed. The study considered some currently employed methods, and employed simulation methodology, to test some alternate parameters of weld current type, time, force and electrode design. In conclusion, it was found that the welding lobe could be widened with the use of optimized welding parameters. Under certain conditions, a larger lobe can be achieved using 2-pulse weld current input over 1-pulse and 3-pulse inputs. Titanium coated electrodes can further increase the width of the welding lobe, allowing an increased range of operating currents during welding. Significantly, lower allowable currents suggest that coated caps may prolong electrode life through lower heat input values. Button pull-out failure mode testing can be achieved using proper set-up without increasing total welding cycle time and electrode force.

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## I. OBJECTIVE

The objective of this project was to increase the width of the welding lobe, ("the welding window"), of Advanced High Strength Steels (AHSS) in resistance welding. More robust and more stable welding parameters would permit the easier adoption of AHSS in production environments.

## II. PROBLEMS IN WELDING AHSS

Automakers and their suppliers have embraced AHSS for their strength-to-weight ratio and for their ability to aid both increased fuel economy and "crash worthiness". However, their use in welding has revealed a number of problems that are a concern to the increased adoption of this range of alloys.

Generally, they have narrower welding lobes than mild and high strength steels. They tend to exhibit higher expulsion, tend to generate higher electrode wear, and tend to exhibit hardening characteristics as well as increased cracking and brittleness. Often fatigue strength is reduced.

Perhaps most annoying of all, the standard measure of quickly measuring weld quality in most steels, the "pull-button test", (where welded sheets are pulled apart, leaving the welded spot weld intact but the parent sheets torn), often fails. While the absence of a "button" in a test is no automatic proof of a poor weld in AHSS, there is increased analysis required in the examination of the interfacial failure.

Indeed, as if the problems above are not enough, steel manufacturers can use different chemical compositions and different processes to achieve the same mechanical specification – and, as a result, create alloys of the same strength with different welding characteristics to which the automakers must adapt.

Thus there is a demonstrable need to assist automakers and their suppliers in generating welding conditions that are more stable, robust, or that employ parameters that allow a "larger welding window" in which to operate.

## III. FINDING A SOLUTION

As a starting point, it was determined that current input type, time, force, and electrode design would be considered.

For current, an AC current of one, two and three pulse current inputs would be employed with no intermediate cooling between pulses. This was based upon the need for high welding rates in a production environment and a subjective judgement as to the efficacy of quick "asperity softening" of the sheet surfaces.

Different weld times of 15, 18 and 21 cycles were chosen, as were weld forces of 4, 5 and 6 kN. These choices were largely arbitrary.

Independent tests (Ref. 1 & 2) have shown titanium carbide coated electrodes (TiCaps™) to have a longer useful "life" and to "stick" less than uncoated electrodes, especially on galvanized and coated steels. It is thought that the coating reduces intermetalic alloying between zinc and related alloys of the sheet being welded and the copper based alloys of the electrode and thus slows the rate of degradation of the electrode (Ref. 3). As a result, titanium carbide coated electrodes were chosen to see how their welding lobe would correspond with those of uncoated CuCrZr electrodes.

Successful resistance welding depends upon the correct use of variables. To aid in the selection of appropriate variables, and as an aid in honing those selections through documentation and experimentation, SORPAS® simulation software was chosen as a precursor of experimental testing (Ref. 4).

For the tests, Dofasco supplied 1.2mm thickness hot dipped galvanized DP600 steel and the University of Waterloo provided the AC pedestal welder with constant current welding controls. A device under the lower electrode measured welding force, and a linear variable differential transformer (LVDT) measured the electrode displacement.

## IV. SORPAS® SIMULATIONS

SORPAS® software was used to run simulations of the dynamic resistance and anticipated nugget size under different welding conditions of current input type, weld time and weld force. A comparison of the 2-pulse current input (with a first pulse of 2 cycles on the left (a) and a 5 cycle first pulse on the right) and the resulting weld nugget simulations from SORPAS® are illustrated below:

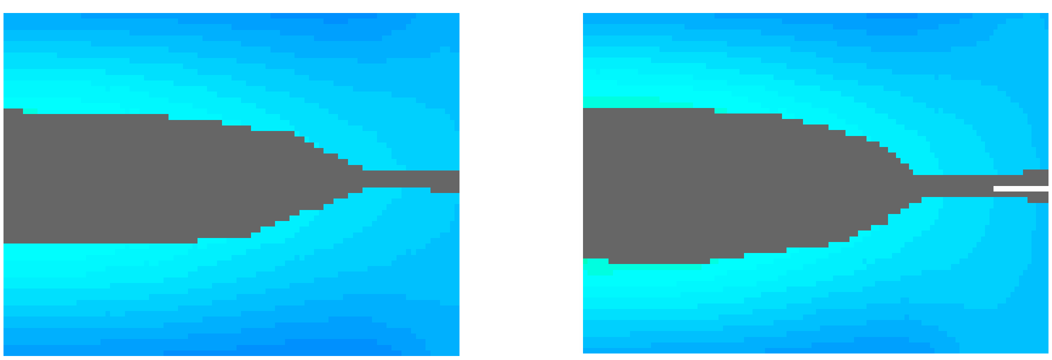

***Figure 1. Nuggets simulated by SORPAS® software, using a 2-pulse current with the left diagram illustrating a 2 cycle first pulse and the right a 5 cycle first pulse.***

## V. WELD CURRENT INPUT

Three types of current input of 1 pulse, 2 pulses and 3 pulses were tested. Stylized representations of the three current inputs are shown below, with the arrows indicating the length of the weld times in cycles of the respective pulses. The vertical axis is the welding current.

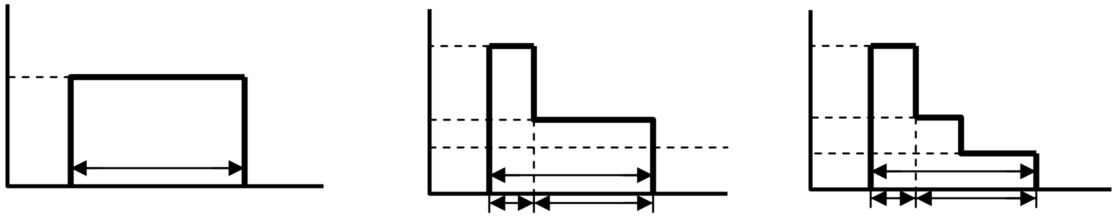

*Figure 2. Types of current inputs tested, from left to right, a single pulse weld, a 2-pulse weld and a 3-pulse weld.*

## VI. WELD TIME CHANGES

Weld times were varied, simulated and tested in the laboratory. Below, the single pulse input current from Figure 2 above (on the left) is illustrated with weld times of 15, 18 and 21 cycles.

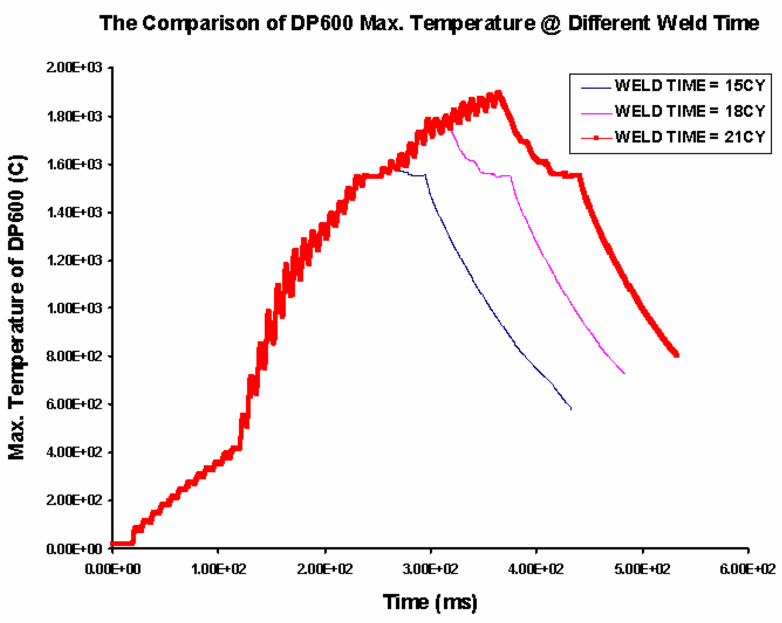


*Figure 3. Maximum temperature of 1-pulse welding with different weld times simulated by SORPAS® software.*

## VII. WELD FORCE CHANGES

Figure 4 below illustrates the simulated of nuggets of weld forces of 4, 5 and 6 kN respectively. Other welding variables were held constant.

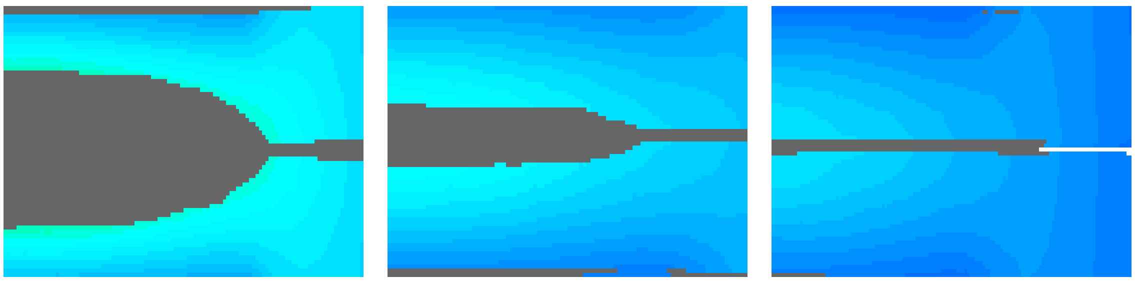

***Figure 4. SORPAS® software generated nugget profiles at 4, 5 and 6 kN respectively.***

## VIII. TITANIUM CARBIDE COATED ELECTRODES (TICAPS™)

Titanium carbide coated electrodes, known for their hard surface that is 7 times harder

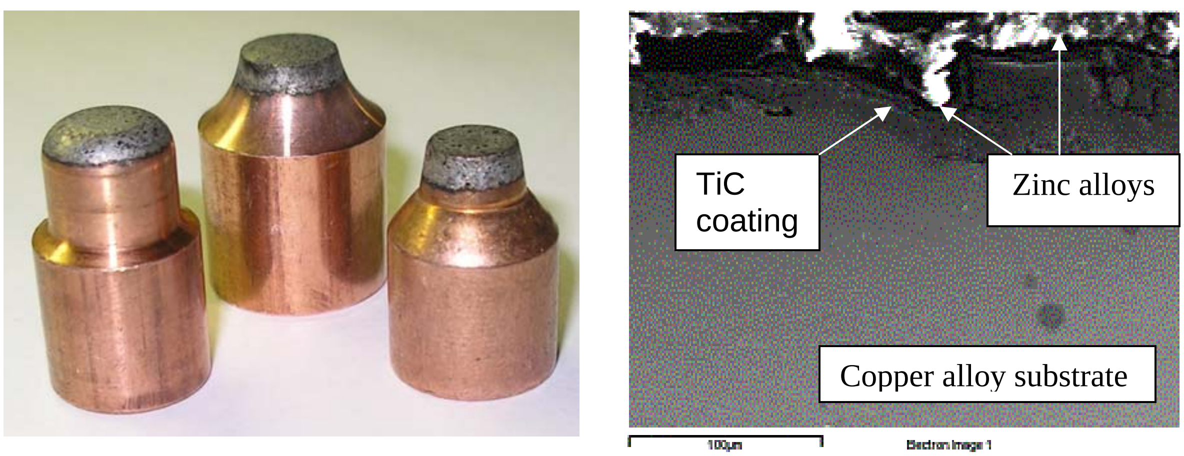


***Figure 5. Left are titanium carbide coated electrodes (TiCap™) and, right, a SEM cross section of a used TiCap™ showing the coating's effectiveness of retarding molten zinc alloys' attempt to migrate, once vapourized in welding, into the copper alloy electrode.***

than copper chromium zirconium (Ref. 5), and its ability to delay electrode degradation (Refs. 6 & 7), were tested for the width of the welding lobe width against similar but uncoated standard copper chromium zirconium electrodes using standard American Welding Society testing procedures (Ref. 8). The tests were designed to measure and compare the relative operable size of the two types of electrodes' welding lobes.

## 1X. EXPERIMENTAL RESULTS

Comparisons from simulations to actual test results were interesting, and, overall, achieved a correlation between simulation and experimental result of approximately 90%. Fine-tuning of the simulations can present even closer results, although this takes additional time. The simulations certainly provided a useful background of related and documented information from which to draw samples and conduct precise test follow-up experiments.

Figure 6 below illustrates the actual test results of 2-pulse welding experiments (see Figure 2, middle diagram) using 2 cycles, 3 cycles and 5 cycles for the first pulse. The diagram lists the welding currents required, in kA, for the various desired diameters of nuggets generated based upon the thickness of the metal being welded, as well as the current level at expulsion. The chart also indicates the welding lobe in the farthest right hand column.

**Comparison of Weld Current Range for DP600 (1.2mm) @ Different WT1 (2-pulse)**

| Diameter (mm) / Weld Current(kA) / Weld Condition | $4\sqrt{t}$ (Minimum) | $5\sqrt{t}$ | $6\sqrt{t}$ | Expulsion | Lobe |
|---|---|---|---|---|---|
| 2-Pulse WT1 = 2 Cycles | 8.3 | 9 | 9.4 | 10 | 1.7 |
| 2-Pulse WT1 = 3 Cycles | 8 | 8.3 | 9.2 | 9.4 | 1.4 |
| 2-Pulse WT1 = 5 Cycles | 7.6 | 8.1 | 8.7 | 9 | 1.4 |

***Figure 6. Experimental results of 2-pulse welding of various first pulse welding times.***

These results above can be compared to the results illustrated in Figure 7 below. The chart below shows the experimental results from using a single weld time of 15, 18 and 21 cycles (see Figure 2, left diagram). The chart indicates that not only that the currents employed in this particular test are generally higher to achieve the same required nugget diameter, but also that the resulting welding lobes for each selected welding time are appreciably more narrow. Such an analysis suggests that the 2-pulse approach may have a significant advantage for lowering welding costs by reducing the time of welding, speeding production and by extrapolation, reducing electricity demand and costs.

A short initial pulse, followed immediately without a cooling period, and then a lower heat pulse, would seem to indicate a method for increasing the welding lobe's width. It seems that the initial pulse need not be a high current. In summary, it appears that a shorter time is needed when a 2-pulse input current is used to achieve the same sized nugget than with a 1-pulse current input.

Weld Current Range of DP600 (1.2mm) @ Different Weld Time

| Diameter (mm) / Weld Current(kA) / Weld Condition | $4\sqrt{t}$ (Minimum) | $5\sqrt{t}$ | $6\sqrt{t}$ | Expulsion | Lobe |
|---|---|---|---|---|---|
| Weld Time = 15 Cycles | 9.45 | 10 | 10.5 | 10.6 | 1.15 |
| Weld Time = 18 Cycles | 9 | 9.4 | 10 | 10.2 | 1.2 |
| Weld Time = 21 Cycles | 8.05 | 8.4 | 9 | 9.2 | 1.15 |

***Figure 7. Experimental results of 1-pulse welding of various pulse welding times.***

Figure 8 below shows the test results obtained when only welding force is changed.

Weld Current Range of DP600 (1.2mm) @ Different Weld Force

| Diameter (mm) / Weld Current(kA) / Weld Condition | $4\sqrt{t}$ (Minimum) | $5\sqrt{t}$ | $6\sqrt{t}$ | Expulsion | Lobe |
|---|---|---|---|---|---|
| Weld Force = 4 kN | 7.55 | 7.8 | 8.4 | 8.6 | 1.05 |
| Weld Force = 5 kN | 8.05 | 8.4 | 9 | 9.2 | 1.15 |
| Weld Force = 6 kN | 8.1 | 8.6 | 9.4 | 9.6 | 1.5 |

***Figure 8. Experimental results of 2-pulse welding at various differing welding forces.***

Interestingly, the lobe widens as the welding pressure is increased, and the current required for a given weld nugget diameter increases. However, anecdotal comments from production people suggest that increasing welding forces at the same time as increasing heat and current are not a practical solution to increasing the welding lobes of AHSS in high speed production, given equipment, time and cost constraints. (For another discussion of the effect of force in welding AHSS, see ref. 9).

A simpler method of increasing welding lobe width can consider the adoption of titanium carbide coated electrodes. Figure 9 below illustrates the welding lobes of both uncoated and coated electrodes.

Weld Current Range of DP600 (1.2mm) @ Uncoated and TiC coated Tip

| Weld Condition / Weld Current(kA) / Diameter (mm) | | $4\sqrt{t}$ (Minimum) | $5\sqrt{t}$ | $6\sqrt{t}$ | Expulsion | Lobe |
|---|---|---|---|---|---|---|
| Weld Time =15 Cycles | Uncoated Tip | 9.45 | 10 | 10.5 | 10.6 | 1.15 |
| | TiC coated Tip | 8.3 | 8.8 | 10 | 10.2 | 1.9 |
| Weld Time =21 Cycles | Uncoated Tip | 8.05 | 8.4 | 9 | 9.2 | 1.15 |
| | TiC coated Tip | 7.7 | 8.4 | 9.2 | 9.4 | 1.7 |

***Figure 9. Experimental results of 1-pulse welding of coated and uncoated electrodes.***

Using a simple one pulse welding operation, the chart above shows that titanium carbide coated electrodes provide a significantly wider welding lobe width (in the order of 50%) over those of similar but uncoated electrodes in actual tests.

More importantly, such an immediate increase in welding range is achieved at a lower overall required current. Lower currents imply lower costs through lower electricity bills as well as lower operating demands upon employed equipment. Figure 10 below graphically represents the increased welding lobe of titanium carbide coated electrodes of similarly uncoated electrodes.

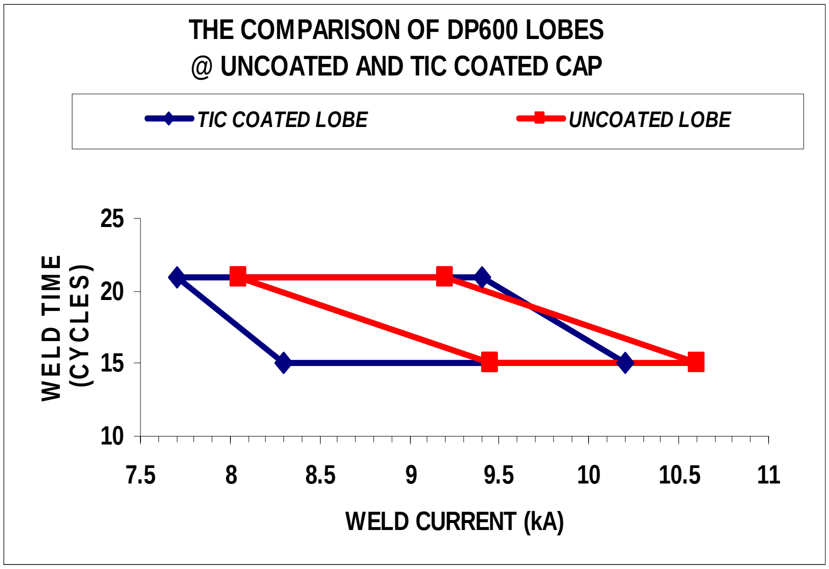


***Figure 10. Experimental results illustrating welding lobe of coated and uncoated electrodes of single pulse welding time.***

## X. CONCLUSIONS

A number of conclusions arise from this study.

First, SORPAS® software was a useful tool that helped predict, analyze, cross-reference and document weld performance.

Secondly, welding lobes can be optimized for AHSS by the use of correct welding parameters.

Thirdly, and more importantly, it is clear that additional work on the types of weld current inputs holds further promise. In the tests performed here, two pulses of differing current intensity without a cooling period achieved significantly better results by requiring a shorter period of time to obtain a given weld nugget diameter than a 1-pulse weld input or a 3-pulse current. In addition, these interim findings suggest that less overall force may also be required for a given nugget size.

Fourthly, a larger operating welding lobe was achieved with the use of titanium coated electrodes (TiCaps™). Since it was observed that titanium coated electrodes operate at lower currents than regular uncoated electrodes, it can be surmised that these lower currents may lower plant electrical requirements and costs, allow for the increased use current "stepping", and thus achieve a longer operating life for the electrodes.

Fifthly, welding "buttons" were pulled in testing. This suggests that the button "pull-out" method of resistance welding testing for AHSS can be employed if proper welding parameters are followed. In these tests, this was achieved without increasing total weld time or electrode force. It was noted that buttons were "shrinkage-void" free. This seems to support the concept that when a sufficient nugget size co-exists with a solid weld, a button pullout will be achieved. In addition, the higher electrical resistivity of DP600 steel may assist in creating larger nuggets.

## X1. ACKNOWLEDGEMNTS

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