Saving Time and Money with Resistance Welding Simulation Software

Software takes into account various strengths and limitations of welding processes and materials to predict optimum welding conditions and joint design

BY KEVIN R. CHAN

Significant time and money can be saved with the use of software that simulates the process of resistance welding. This article provides specific examples of how this has been done with the finite element modeling software called *Sorpas®*. This software has been used to assist in the design of resistance welding parts and joints. It determines welding parameters, how the welding parameters can be optimized for various conditions in production, and forecasts the microstructure of the parts after welding.

This software is currently in use by major automotive and manufacturing companies such as GM, Ford, Honda, Volkswagen, Chrysler, Mercedes Benz, Volvo, Peugeot, Citroën, Bosch, Siemens, and ARO. These and other companies use the software to reduce the time and money in resistance welding, from the design stage to production floor.

Market Challenges

Clearly, there is an imperative to reduce costs and the "time to market" in an age of increasing globalization and competition. At the same time, many new steels that are both stronger and lighter are increasingly being employed to raise fuel economy and to provide greater crash protection. These driving forces for change and improvement bring problems of increased design and welding complexity when these steels are used.

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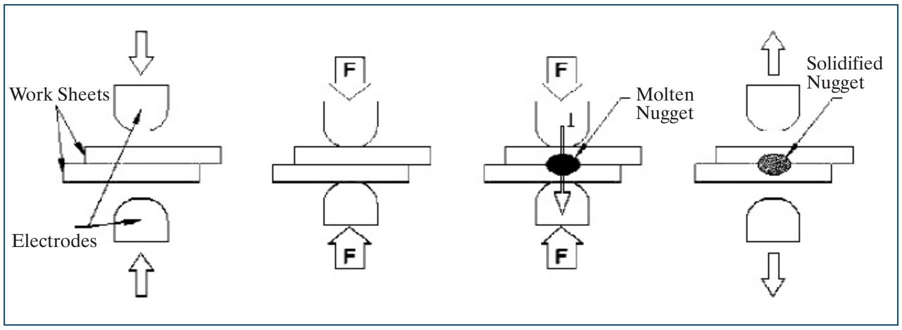

Fig. 1 — The basics of the resistance welding process.

Resistance Welding

Resistance welding is an inexpensive process that requires no shielding gases or filler metals to create a metallurgical fusion bond. An electric current is passed through the metals to be welded after a force is applied, and their innate resistance to the current generates sufficient heat to create the weldment. This is shown in four basic steps in Fig. 1.

How Simulation Works

The software uses the power of modern microprocessors to fully articulate all the variables in resistance welding. It does this by considering and calculating all the variables through four separate yet fully coupled models: 1) the electrical model, with its current/voltage distribution and heat generation; 2) the thermal model, with its heat transfer and temperature distribution; 3) the metallurgical model, with its temperature-dependent properties and phase transformation characteristics;and 4) the mechanical model with its deformation, stress and strain distribution in the contact areas, electrodes, and geometries of the workpieces (Ref. 1). Each calculation or iteration involves the use of all four models as shown in Fig. 2.

The operator enters into the computer the geometry of the parts, identity of the materials to be welded, the interface conditions, and the electrodes employed. In another window, the user enters the welding parameters to be used, such as force, time, and current. The user can also ask the computer to generate the required welding parameters, and automatically or manually alter the extent of accuracy sought and the overall simulation controls. When instructed, the computer generates welding parameters, welding lobes, and optimizations, based upon the instructions it has received. All input variables are kept in common welding parameters and terminology. In Fig. 3, an example of one of the printouts available, which provides a summary of the simulation, is shown. Other reports include real-time animations of the simulated weld, showing such data as deformation and heat and strain distributions.

Design Stage

In the design phase, the characteristics and limitations of various joining processes and materials are weighed and selections made. Engineers consider the parts, their design, and how they might fit together. Today, especially in the automotive sector, with our future oil supplies uncertain, more and more attention is being applied to thinner and stronger alloys to take a larger role in manufacturing. Generally, all of this analysis has to be done more quickly than in the past.

Detailed below are examples of how three companies, Volkswagen, a manufacturer of micro welded parts, and Honda saved time and money at the design stage by using this simulation software. They used it to visualize the inner workings of the welding process, thereby reducing testing and costs, while at the same time optimizing the welding parameters for long-term performance and quality.

Simulating Projection Welding at Volkswagen

Volkswagen's patents governing *Resistance Welding With Additional Elements* was achieved with the software (Ref. 2). These patents can cover welds in dissimilar metals where additional material is inserted at the faying surfaces.

The software was able to reduce the testing of their hypotheses by simulating projection welding that acts in a similar fashion to their "additional elements." Volkswagen believed it would be very time consuming and expensive to consider the influences of heat, force, and current on the myriad different materials considered for this process (Ref. 3). The software was able to significantly reduce and focus the testing window. Volkswagen's drawings (Fig. 4) illustrate how modeling and simulation of projection welding helped achieve production welding parameters for its innovative process.

Other companies have used the software to help design the actual part used in production (Ref. 4). In the drawings (Fig. 5), it can be seen how one company has used different designs of insulation (blue) in the part (on the left) to generate different weld characteristics after simulation (on the right). Modeling and simulation of the differing part configurations were able to show the differences in how the heat was generated in the parts and, subsequently, how the weld initiated and grew. Therefore, the engineer could choose which design looks the most promising and pursue it with additional testing. The simulations can greatly decrease the time to market, while at the same time cre-

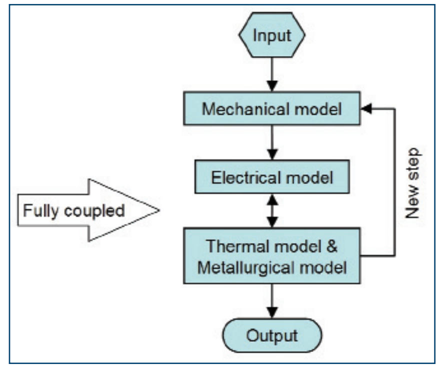

Fig. 2 — The coupling of numerical models.

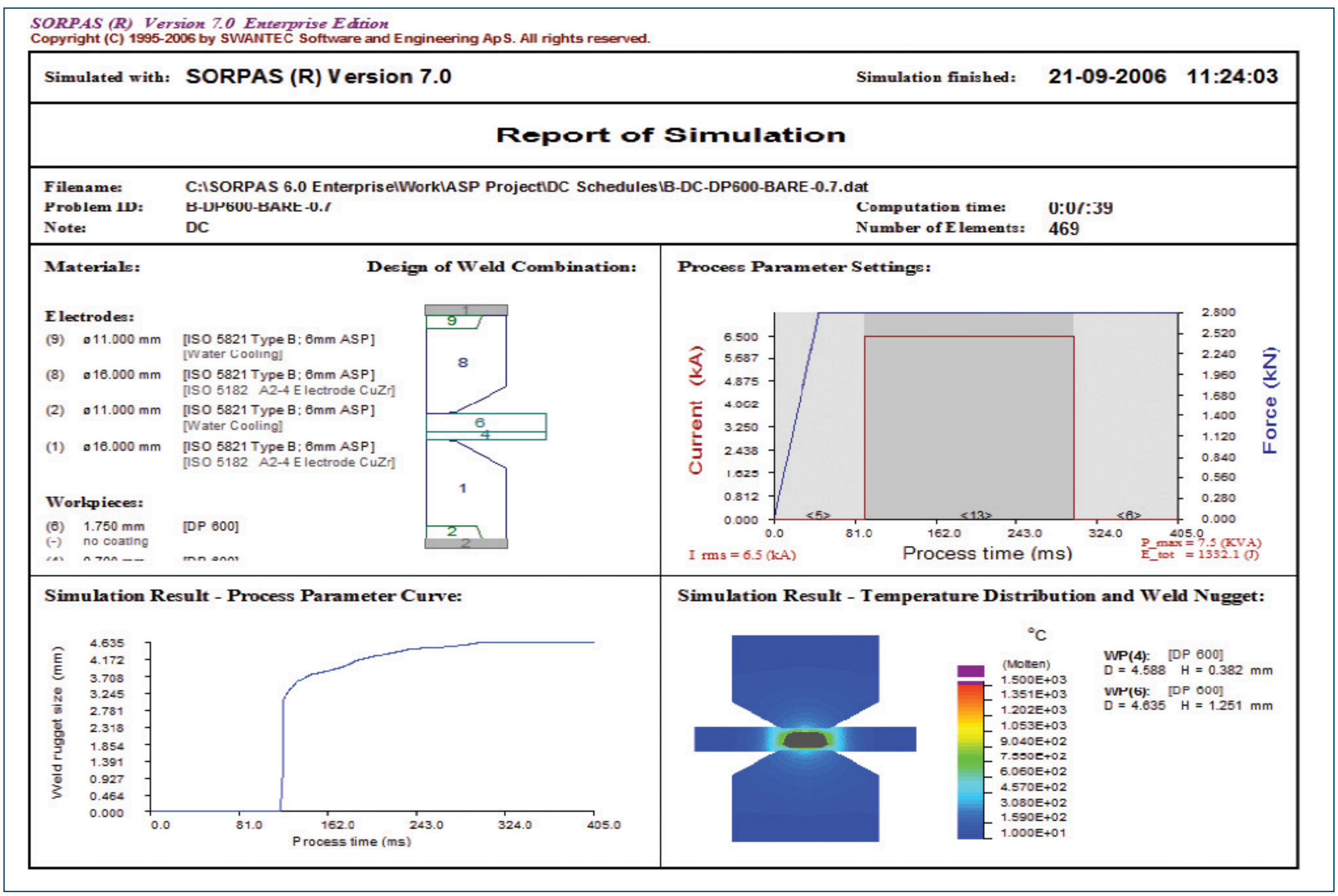

Fig. 3 — Report summarizing test results.

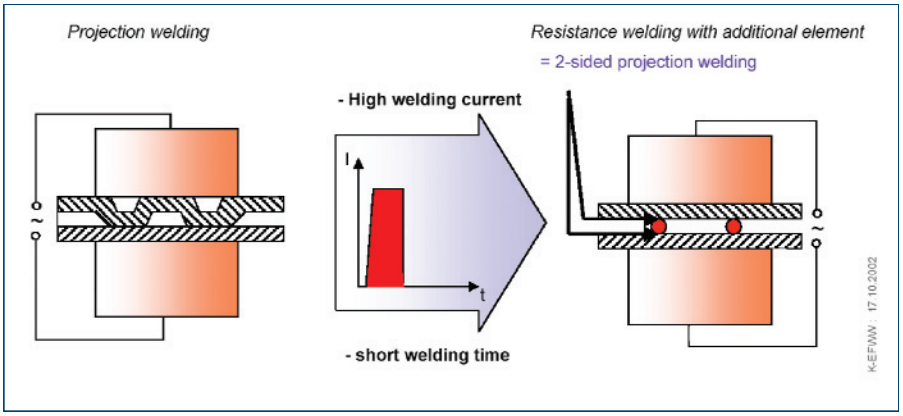

Fig. 4 — Illustrations of Volkswagen's patents for Resistance Welding with Additional Elements.

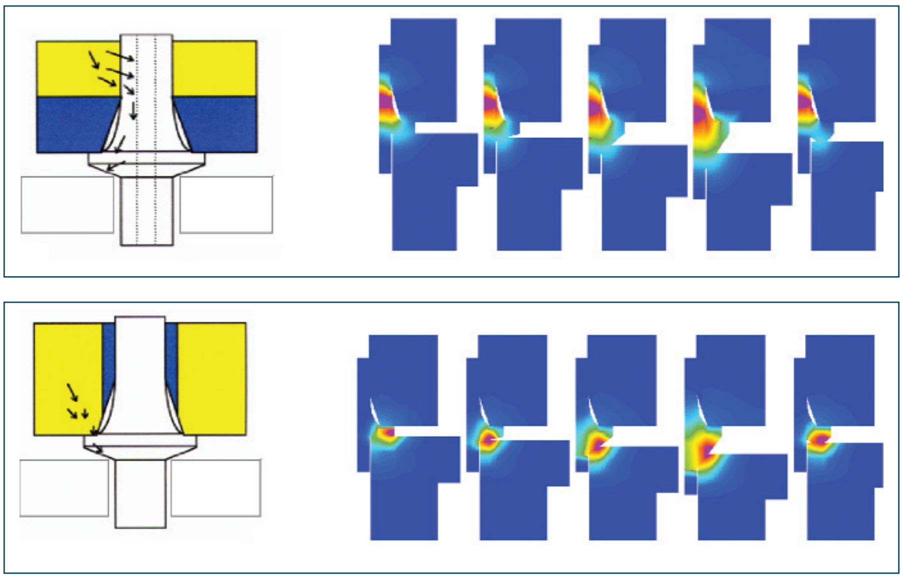

Fig. 5 — Example of using different insulation designs (left) to generate different welding characteristics.

ating a paper trail where choices made are appropriately documented, with their accompanying result noted.

Reducing Test Requirements at Honda

Honda used the software to reduce the number of tests needed to find an inexpensive way to join the hem of an exterior car door and its inner panel without marking the outer surface. The software was used to aid in the optimization of welding parameters and projection design for an indirect hem projection weld (Ref. 5).

In this case, physically prototyping the many different configurations and testing the actual parts was not economically sound. Without simulation, the choices available for welding parameters of a hem projection indirect weld are daunting and perhaps unmanageable with the newer coated steel alloys. However, the software was able to reconfigure the electrodes and tools to accommodate any resistance heating process. Figures 6 and 7 show Honda's design. The software accurately estimated the effect of different welding parameters and projection nipple heights that would produce an indent-free outer surface. This was possible by running a series of simulations with certain variables altered.

Anticipating New Materials

The performance characteristics of some new TRIP and DP steels alter when they are welded. When these new complex phase steels are made, their strength and character arise from the unique microstructure resulting from controlled cooling and heating. The fusion nugget and heat-affected zone present a temper-

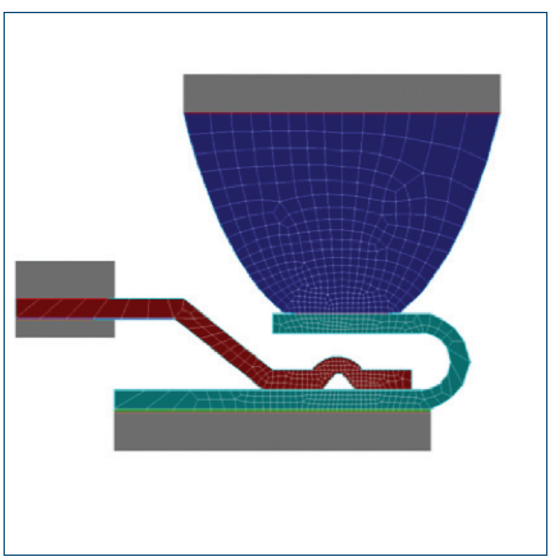

Fig. 6 — Geometric mesh generated by the software for finite element modeling.

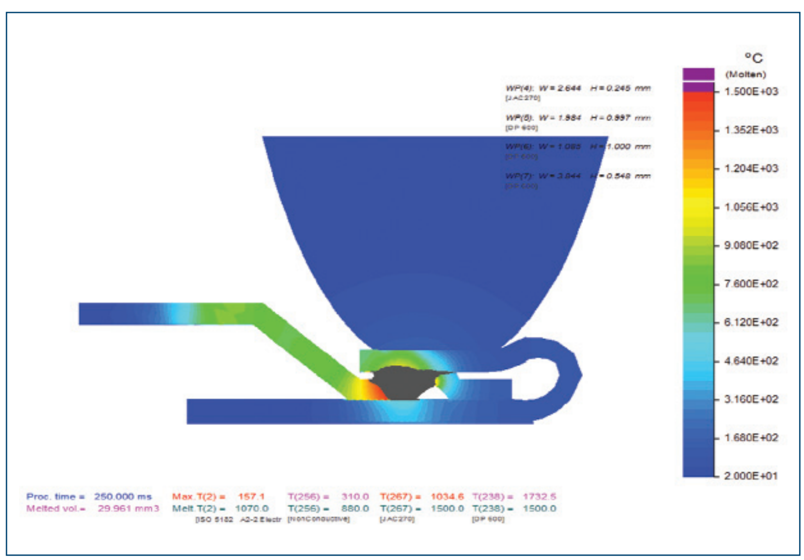

Fig. 7 — A finished simulation illustrating a specific combination of welding parameters and projection designs.

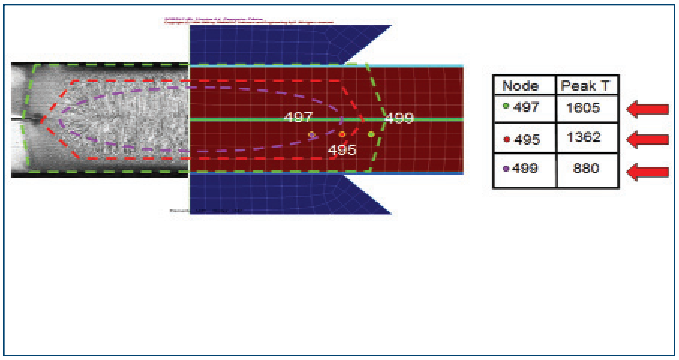

Fig. 8 — A metallographic photograph and a simulation showing peak temperatures in different regions of the weld and HAZ.

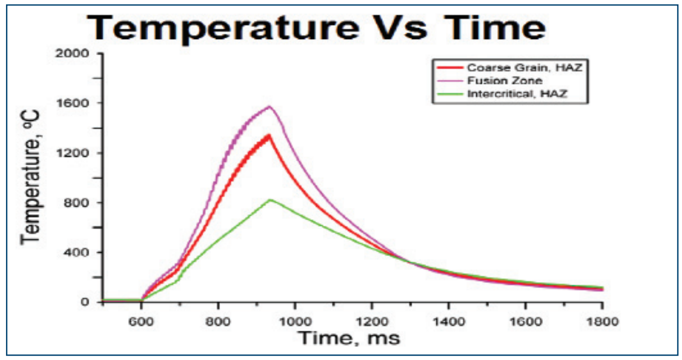

Fig. 9 — Graphs indicating time and temperature during the welding of specific sites, or nodes, of the weldment (see Fig. 8).

ature range from melting to slight warming around the weld area. This temperature history destroys the carefully created microstructure that gave rise to the steel's character in the first place and can also lead to other problems such as hardening and cracking. The cooling rate of an advanced steel is often critical to its performance and microstructure. Another issue may be that there is a DP steel welded to an high-strength low-alloy (HSLA) steel, creating a weldment with an unknown mixture of two alloys in the weld.

Thus the cooling rate of a weld in an advanced high-strength steel may adversely affect the performance of that steel in a crash. With these types of issues in mind, the University of Waterloo is working with Sorpas® to predict the microstructure, and hence the performance, of a weld in simulation (Ref. 6).

Figure 8 is an amalgamation of a metallographic photograph of a weld performed in the university on the left which has then been compared to the earlier simulation on the right to confirm its reliability. Dotted lines indicate the overall accuracy of the simulation. Certain nodal points in the simulation are indicated on the drawing, and the simulation indicates their peak temperature (far right).

These peak temperatures are then generated as graphs (Fig. 9), which indicate the coarse zone of the HAZ, the fusion zone, and the intercritical HAZ. Then they are referenced to published constant cooling diagrams (CCT), a copy of one which is reproduced in Fig. 10. Colored dots on the CCT in Fig. 10 tie into the colors on Figs. 8 and 9, indicating the various regions of the weld, based upon peak temperature. It is noteworthy that the simulated peak temperatures of the weld tie into the CCT diagram and the metallographic photographic record of the weld.

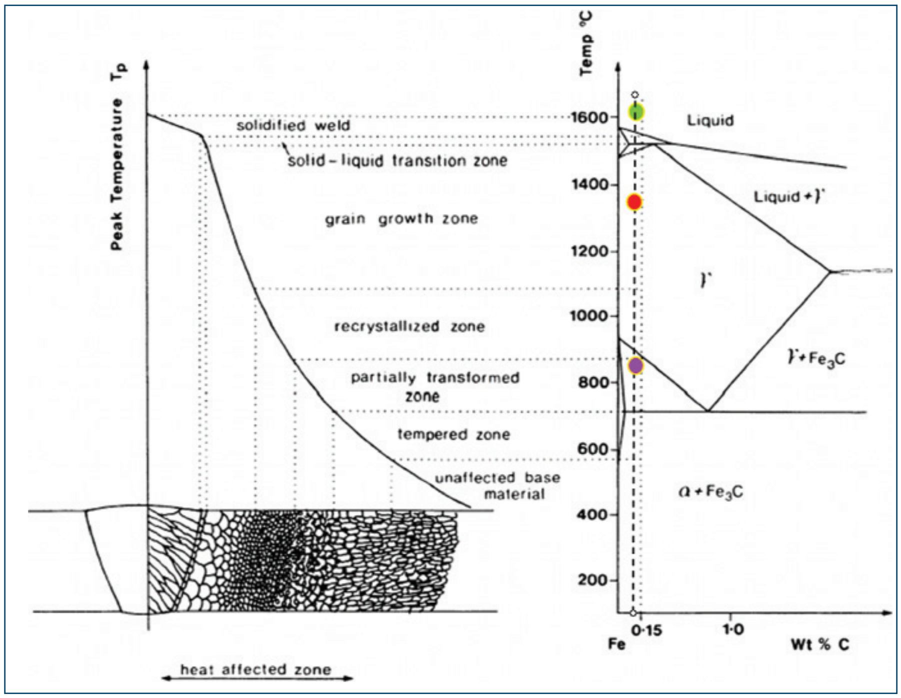

Fig. 10 — A published constant cooling diagram indicating the peak temperatures from Figs. 8 and 9.

Production Stage

Described above is how this software can help reduce time and money spent in the design and prototyping stages of new products and new materials. The greatest use, however, has proved to be in the day-to-day use of the software as an aid to increasing stable and consistent production and the optimization of welding parameters.

As an example, take the parts in Figs. 8–10. Let us suppose that we want to change the peak temperature of the weldment and thus control its cooling rate. The software can predict changes in the resultant microstructure with changes in the length of heat or numbers of pulsed heat inputs. Figure 11 shows results from simulation for the temperature history in the coarse-grained HAZ and the resultant changes to peak temperature and cooling rate based upon increments in weld time of a second weld pulse. Thus it becomes easy to adjust and document changes and improvements in a production setting (Ref. 7).

The production environment is primarily concerned with optimizing welding parameters and to maximize and stabilize production. Optimization is an ongoing process, as parts will have variances in their fit and setup; and the materials themselves will vary both in their surface preparation, cleanliness, and appearance as well as in the materials from which they are made (Ref. 8). Therefore, it is every engineer's desire that he or she can find the best spot in the weldability lobe to gain that overall consistency.

Automotive Parts Supplier Optimizes Welding Variables

As an example, a North American Tier

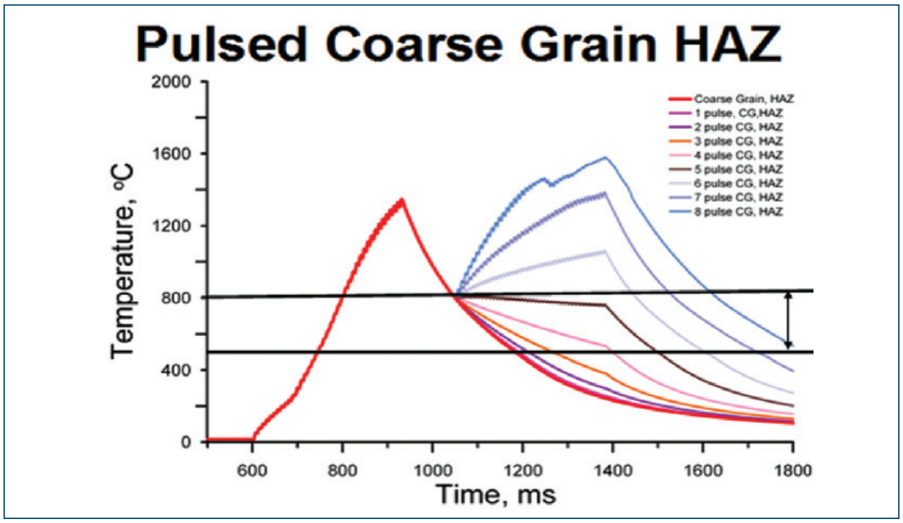

Fig. 11 — Variations in the length of a postweld tempering pulse of a weld are graphed for peak temperature and cooling rate.

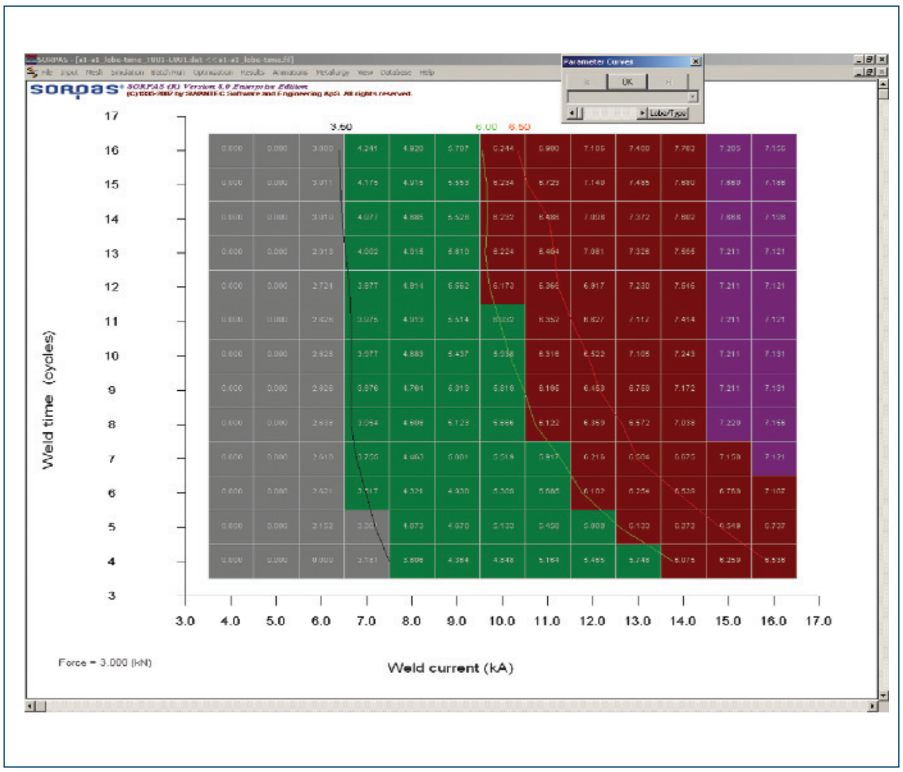

Fig. 12 — Weldability lobe diagram.

1 automotive supplier that is currently welding a new line with DP600 steel found that its initial welding lobes were very narrow and that the welding heat was too high, which caused not only shorter electrode life but also transformer duty cycle issues. In addition, the company had limited time and resources to deal with problems of poor quality welds, inspection, and repair (Ref. 9).

The software has a function to automatically generate weld current optimizations based upon a requested size of weld nugget. Complete weldability lobes are calculated in accordance with ISO 14327:2004. The weldability lobe generated by the software has solid colors indicating risk of expulsion while also indicating the nugget size. It also indicates nugget width at the convergence of the weld time and weld current. Purple indicates electrode melting, red shows expulsion at the interface between sheets, green for welds, and gray for no welds — Fig. 12.

The generation of these weldability lobes was then used as an initial guide to set individual welding machines. It was found that the simulations were, on average, 90% accurate. The company also adopted titanium-carbide metal matrix composite coated electrodes, which were found to have a wider welding lobe than uncoated Class 2 electrodes. The company believes that it has saved $100,000 with the simulation software. The savings came from the following:

1) reduced costs with fewer tests,

2) reduced scrap and wasted time,

3) reduced costs for production maintenance problems,

4) reduced time to respond to OEM requirements,

5) reduced time for production running, settings determination, and optimization,

6) improved weld quality and production stability, and

7) fewer problems and misunderstandings and more accurate and documented procedures.

Conclusions

This simulation software for resistance welding, in the hands of a qualified engineer, can significantly reduce the time and expenses of developing new designs and materials, establish better process parameter settings, and improve troubleshooting and weld quality.

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