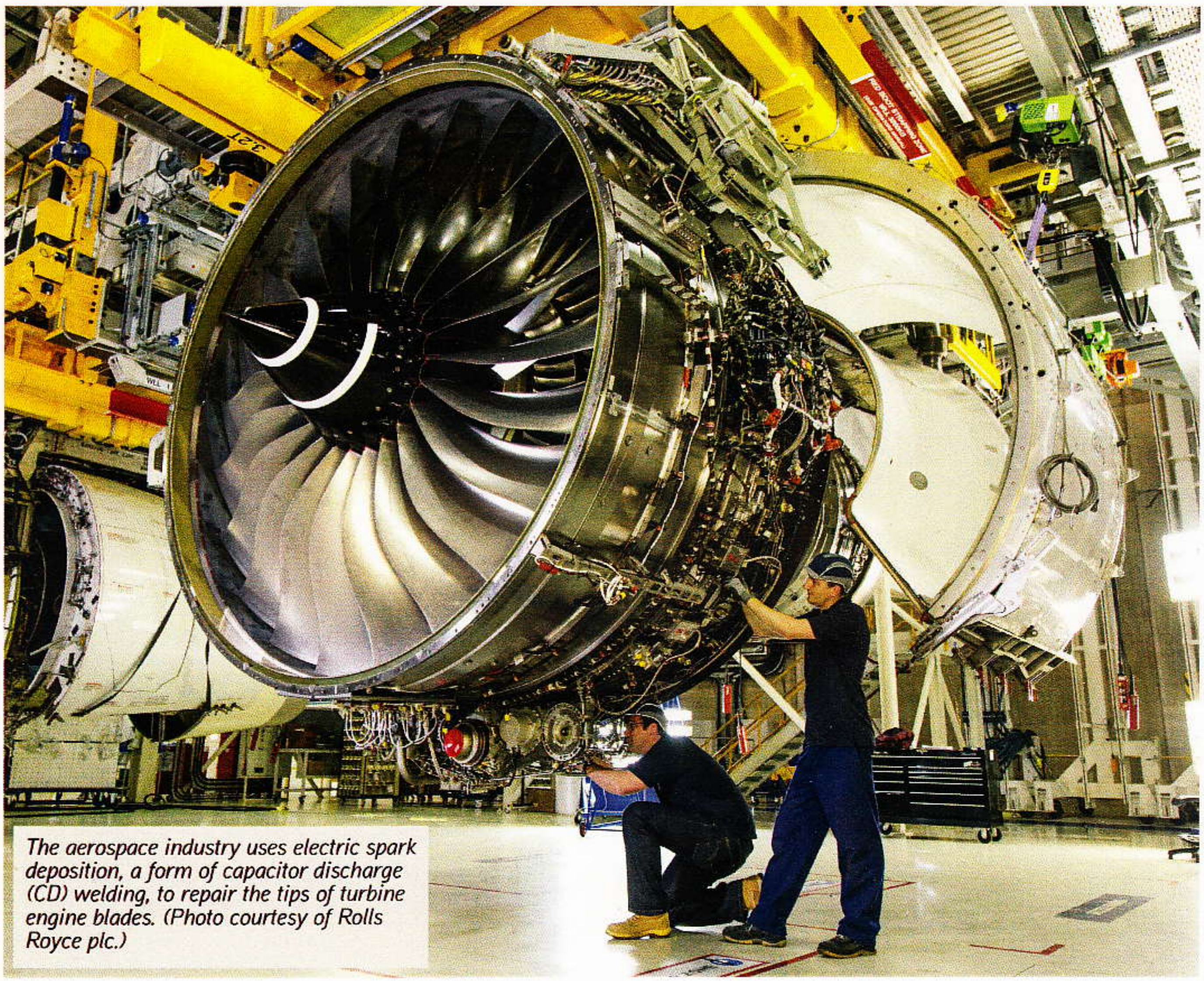
The Current Rise in the Use of Capacitor Discharge Welding

BY NIGEL SCOTCHMER

Capacitor discharge welding is showing advantages for welding hot-stamped boron steels for use in the automotive industry

The automotive industry in North America has been abuzz recently with talk about capacitor discharge (CD) welding. The main reason is that the light-weighting necessary to achieve the U.S. Corporate Average Fuel Economy (CAFE) standards, combined with the need for crash-testing robustness, has led to the adoption of increasing amounts of hot-stamped boron steels in the manufacture of automobiles (Refs. 1, 2) — Figs. 1, 2. These steels are often difficult to resistance weld efficiently as the strength of the weld achieved is not always easy to measure (simple chisel testing doesn't work well with such hard material), the welding force is high (often previously used welding guns now have insufficient force), and the typically uneven aluminum-silicon (AlSi) coating on the steel is particularly aggressive to shortening electrode life. Projec-



The aerospace industry uses electric spark deposition, a form of capacitor discharge (CD) welding, to repair the tips of turbine engine blades. (Photo courtesy of Rolls Royce plc.)

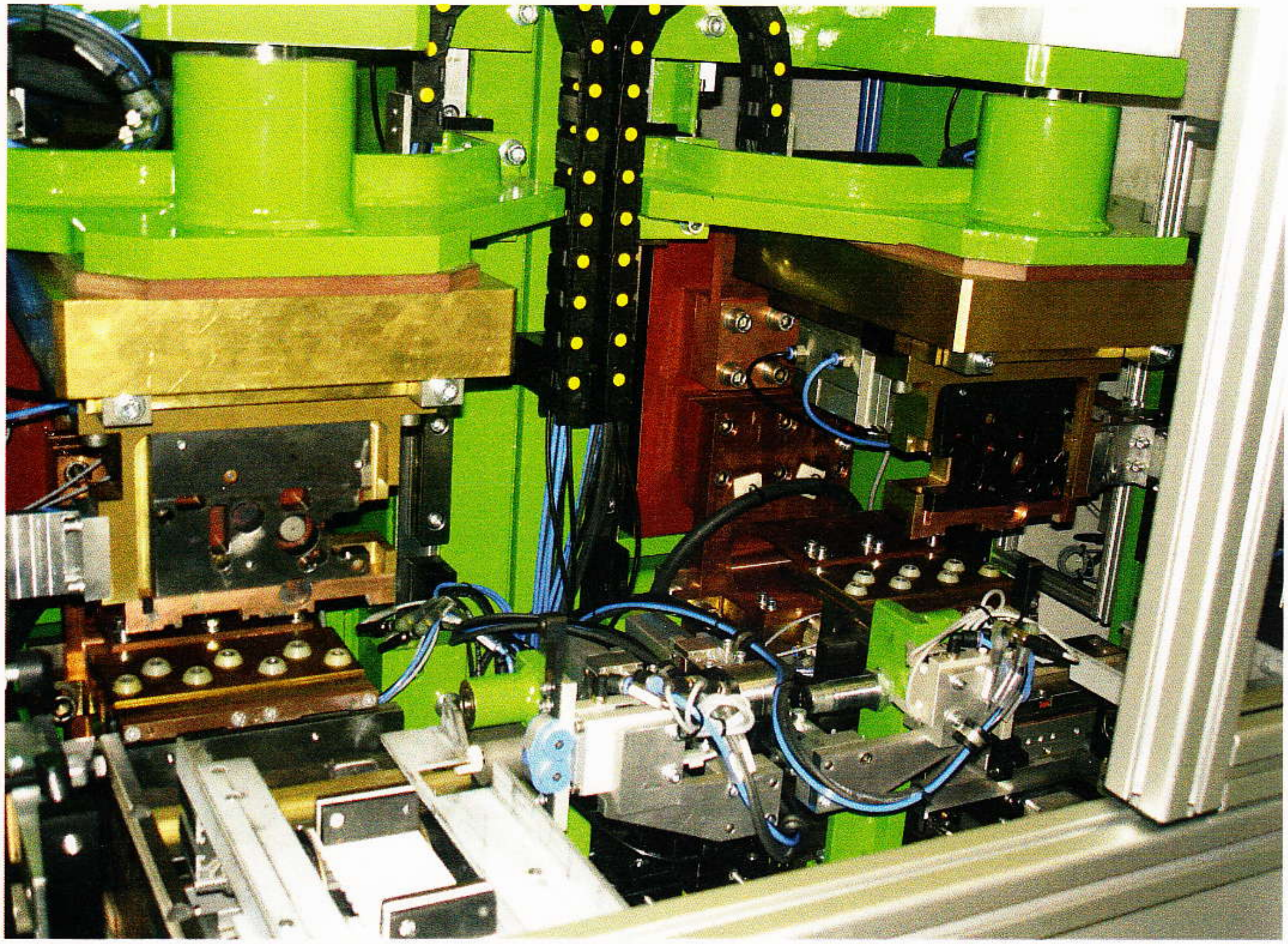


Fig. 1 — Tooling used in a CD welding machine. (Photo courtesy Kapkon GmbH.)

tion welding of forged projections into the substrate is especially troublesome, largely because helpful literature is limited, and welding standards are nonexistent. In such cases, CD welding has proved to be efficacious in welding these boron steels in both the "as-received from the mill" and in the "hot stamped" condition (Ref. 3), while being especially effective for fasteners.

The idea behind CD welding is the relatively slow storage of energy that is then released very quickly, permitting extremely high currents in milliseconds. Capicitor discharge welding has been widely used in many countries for many years, especially where electricity is expensive or the electrical grid itself is unreliable. In fact, its use is increasing in many applications for what used to be regular alternating current (AC) or mid-frequency direct curret (MFDC) applications (Ref. 4).

The rapid release of energy has a number of advantages. No cooling water is needed as the short time of energy flow ensures the adjoining material is not heated. Beside making electrodes last longer, this has the accompanying benefits of not annealing, bending, deforming, and, often, of not even marking the material being welded. For resistance projection welding, the short current rise time is ideal for creating the weld nugget(s) before the collapse of the projections is complete. In addition, machine setup and the training of operators is relatively easy and quick.

The aerospace industry is increasingly using a form of CD welding, called electric spark deposition (ESD), to repair the tips of turbine engine blades for clearance to maintain compression pressures in combustion chambers (see lead photo). As these blades turn, frictional contact wear can increase clearances between the blades and the nacelle, reducing compression pressure in the combustion chamber and increasing fuel consumption. At the same time, to reduce fuel consumption, newer engines have higher compression pressures and higher temperatures, requiring more expensive materials and, consequently, more expensive engine components. When the blades wear, ESD can be used to build the weld metal up to original dimensions without replacing

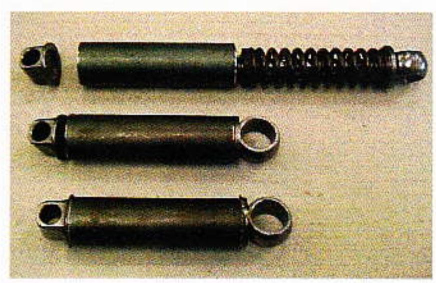


Fig. 2 — CD welded parts showing no marking after welding. (Photo courtesy Kapkon GmbH.)

The idea behind CD welding is the relatively slow storage of energy that is then released very quickly, permitting extremely high currents in milliseconds.

the entire blade. Since ESD welds have no measurable heat-affected zone, they do not alter the microstructure of the adjoining or base material, thus permitting repaired blades to have the same mechanical properties as the original ones. With new jet engines' performance sometimes guaranteed for 20 years, maintaining the advertised frugal fuel consumption figures and minimizing maintenance and repair costs is essential.

An aspect of CD welding is the increased ability to weld dissimilar metals. One such example is Huys Industries' ESD welding of a titanium carbide (TiC-) based cermet to copper alloys such as the copper-chromium zerconium (CuCrZr) used in resistance welding electrodes (Ref. 5) — Fig. 3. The military also frequently uses ESD; both as a replacement for hexavalent chromium coatings and as a battlefield repair on submarines and even combat tanks. Components repaired in situ can be as diverse as submarine steering and diving control rods fabricated from K-Monel™, Abrams tank M1A1 cradles fabricated from 4130 steel, and helical gear shafts (Ref. 6). Many of these welds can be done in air, without shielding gases (Ref. 7).

Why does capacitor discharge work so well for projection welding of hot-stamped steels? Resistance projection welding employs some of the characteristics of hot-forge welding, which has been around since the Bronze Age, and the metallurgy hasn't changed. Heated metal is pressed by force, and as it cools quickly it forms a fine-grained microstructure and a good metallurgical bond. Because of the forging aspect and movement of the weld parts together during the weld, the applied weld force must be very carefully maintained as a "follow-up" force to yield this fine microstructure. This force must also be as evenly distributed as possible across the projections to promote an even collapse.

Fig. 3 — A benefit of CD welding is its ability to weld dissimilar metals such as the TiC-based cermet to copper in these resistane welding electrodes. (Photo courtesy Huys Industries Ltd.)

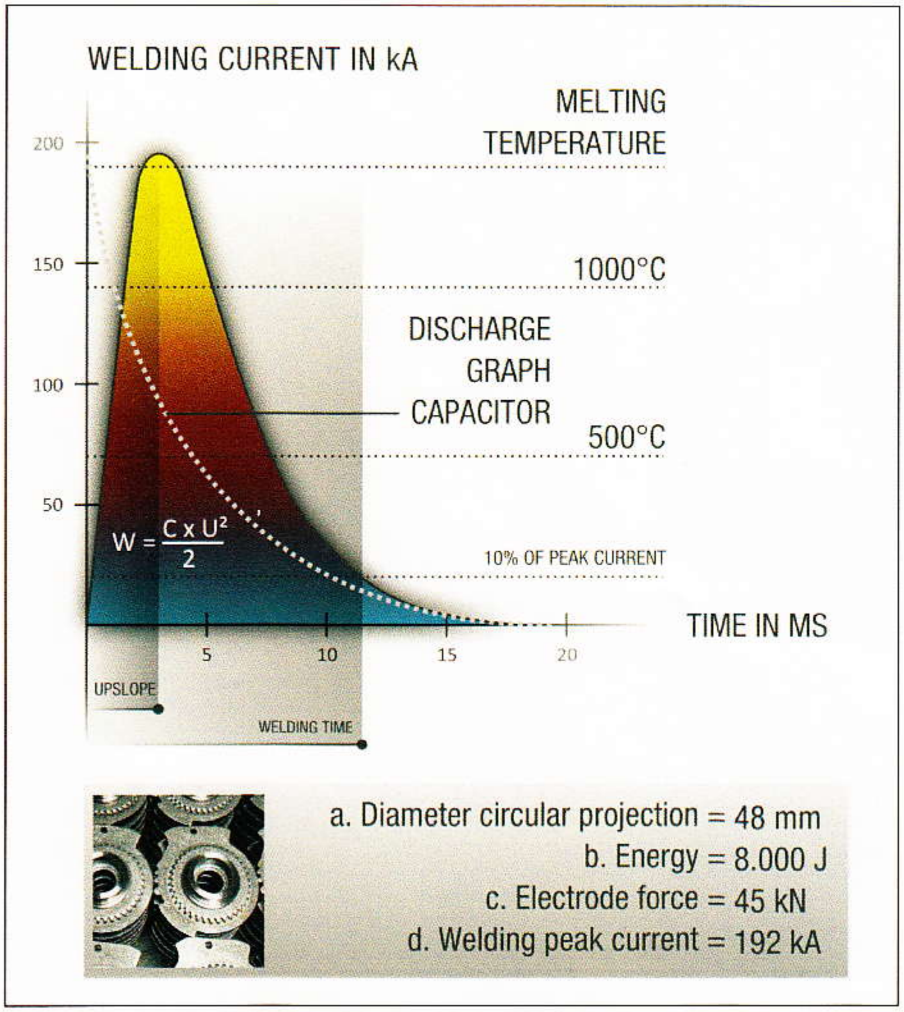


Fig. 4 — Graph of the heating process for CD welding.

The process typically involves energy being fed from a charged rack of capacitors by a thyristor to one or more transformers. The charging time for the capacitors is up to 1.5 s, and welding times are between 2 and 10 ms. When the capacitors are instantly discharged, the welding current and the temperature at the welding joint rise rapidly, and with high contact resistance of the AlSi coating on hot-stamped steels, the fast "up-slope" heats only the projection area to the melting point — Fig. 4. In fact, another advantage of CD welding is the ability to have a high secondary voltage of up to 45 V. This higher voltage helps to crack isolating coatings and assists in reliable welding. Because of the thermal inertia, the joint is welded before the material around it is warmed by conductive heating. As a result, only the projections of the fasteners exhibit noticeable heat effects. The speed of the secondary current rise is the main feature of CD welding. Incidentally, this rapid and localized heating has given CD welding the nickname as a "cold" welding process. Of course, focusing energy to the actual welding joint means less energy is lost and there is the ability to gain higher power efficiency. Let's look at some typical CD welded threaded fasteners for hot-stamped boron sheet steel in an automobile to see under which conditions it works so well.

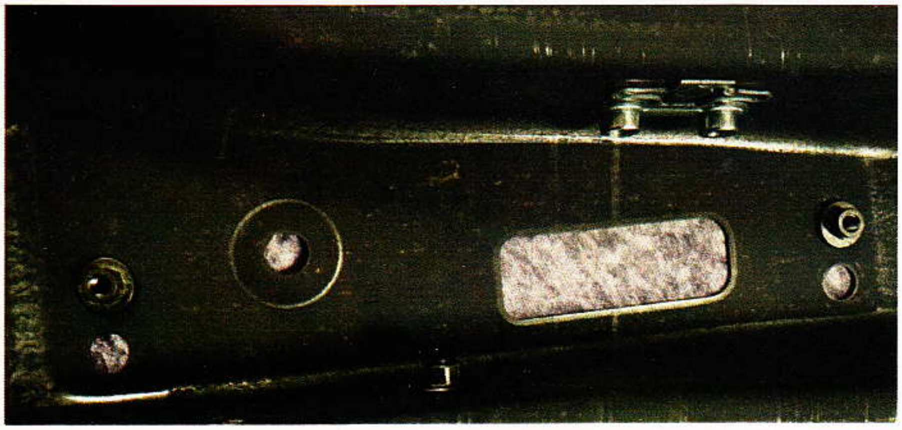


Fig. 5 — Automotive B-pillar and close-up in hot-stamped boron steel. (Photo courtesy Kapkon GmbH.)

For a typical hot-stamped steel such as 22MnB5, a precut blank is heated to about 950°C in an oven for up to 10 min after which it is formed and rapidly quenched in a press die — Fig. 5. A typical hot-stamped steel begins as a steel with good formability after annealing, which, after austenitizing and subsequent die quenching, forms martensite, drastically increasing the hardness and strength of the part. To prevent scaling of the steel after its heat treatment, a coating of AlSi is applied. The AlSi coating has low conductivity, which is affected by iron atoms diffusing into the coating during the baking process. The metallographic photograph in Fig. 6 illustrates the unevenness, cracking, and porosity of the AlSi coating after hot stamping that can easily lead to unpredictable welding results even with consistent welding parameters as individual welds may have differing initial resistivities.

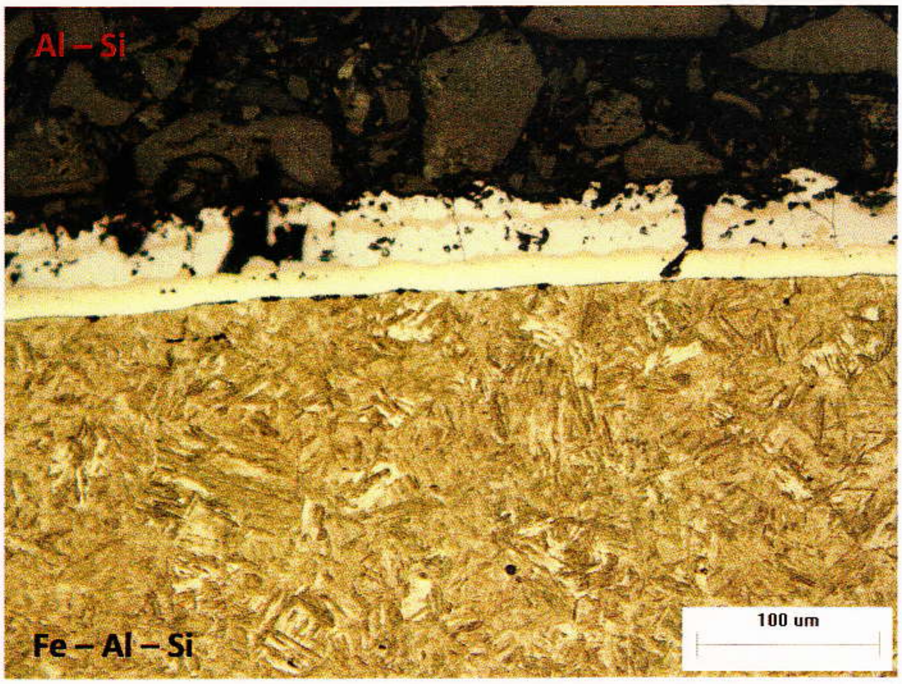


Fig. 6 — The unevenness, cracking, and porosity of the AlSi coating after hot stamping can lead to unpredictabel of welding results. (Hou et al., University of Waterloo.)

Generally, a pulsed welding schedule is used to weld hot-stamped steels, and regular spot welding works well without major problems, as relatively longer welding times are appropriate and manageable with traditional spot welding equipment. However, projection welding of fasteners like spacers, screws, nuts, and thread-bushes is problematic from a production stability point of view as a result of the effects of the AlSi coating. Faced with quality issues, some companies have resorted to trying to spot weld fasteners prior to hot stamping, removing the AlSi coating at weld positions by manual grinding after hot stamping, or even employing more expensive welding processes, such as arc welding, to ensure quality is maintained.

However, higher costs from additional handling or ancillary processes quickly bring the wrath of accountants. Capacitor discharge welding can significantly reduce costs, increase production rates, and, as has been previously noted, improve quality and consistency. Beside being quick, easy, and requiring little training or setup, the CD process is relatively foolproof if certain fastener design characteristics are followed.

As a rule, high projections on the fastener are better, as the AlSi coating delays the upslope, thus allowing the projection to be pressed down before the melting temperature is achieved. In addition, it is a good idea to have as much distance as possible between the projection and any thread. This is because the heating process cracks the AlSi coating and there is the risk of weld spatter. Centering rings or pilots are generally to be avoided as an improper contact can lead to poor balancing of the welding energy that can lead to unreliable weld strength. If a centering ring is required, segmenting the ring is helpful. Likewise, a wider contact flange is useful to control the rapid heatup of CD welding without running the risk of overheating the thread. Flat contact areas of the projection are helpful (as opposed to sharp or pointed projection ends), as the strength of the steel will not be affected by the welding force. Electrode material is usually a Class 3 material since its increased hardness better resists hard AlSi dust. Finally, firm jig and machine structure are necessary for weld repeatability and consistency (Refs. 8, 9). An optimal nut, an M8, is shown in Fig. 7.

The increasing computerization of welding control is leading many com-

Fig. 7 — An example of an optimal fastener for CD welding to hot stamped steels.

panies to adopt in-line monitoring as a less expensive and safer method of ensuring product quality. A typical system records the voltage, current, resistance, force, and deflection — Fig. 8. Samples are first welded and manually tested (pull-out methods are recommended vs. torque testing) to confirm the chosen parameters, and the references measured and fixed. The software then calculates the average, determines the range of all the curves, and sets limits, documenting all production and exceptions for review and retention. Quality is maintained as references are predetermined and tests are neither random nor subjective.

In conclusion, since dissimilar and emerging materials are likely to be used more frequently in the future, the use of CD welding with its unique rapid welding process, assured repeatability, and relative ease of use will continue to grow. As Gould (Ref. 10) noted, the potential use of supercapacitors for general resistance welding applications will only increase the extent to which CD welding is reviewed and considered in the years ahead. WJ

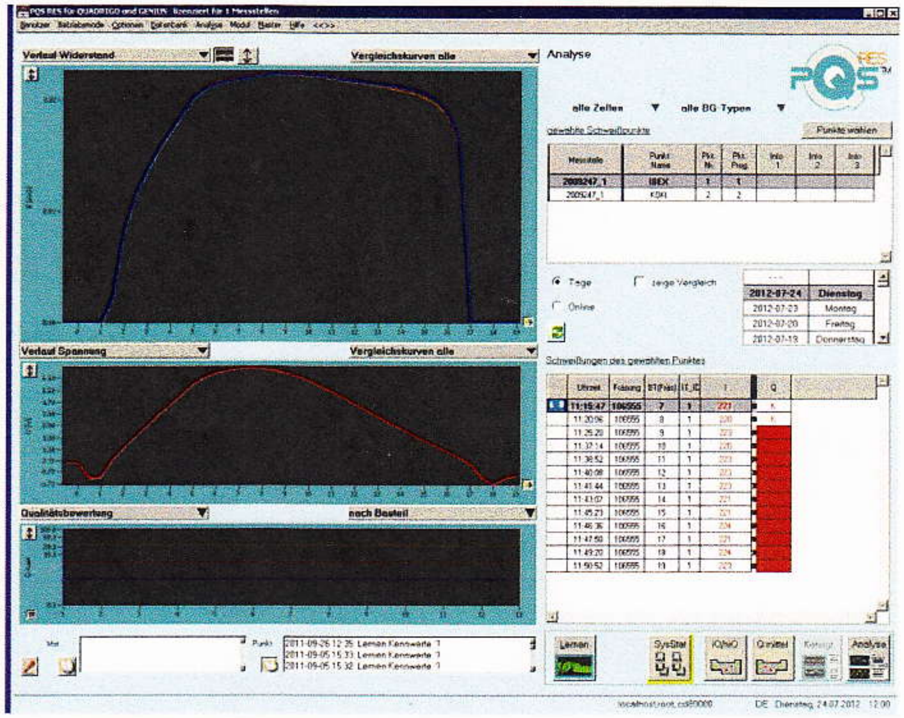


Fig. 8 — An example of the reports from a quality-tracking software. (Photo courtesy of Harms & Wende GmbH & Co. KG.)

References

1. *www.epa.gov/fueleconomy.regulations.htm.*

2. Von Wurtemberg, M. J. 1994. Lightweight materials for automotive applications. *I&SM* 21(8): 11–21.

3. Hou, J., Chan, K., Scotchmer, N., Zhou, N., and Gerlich, A. P. 2014. In-situ tempering of hot stamped martensitic steel. *Proceedings of AWS Detroit Section's Sheet Metal Welding Conference XVI*, Livonia, Mich.

4. Lolli, A. 2014. Optimisation of the spot welder electric absorption thus improving the welding process quality and reducing TCO. *VIIIth International Seminar in Advances in Resistance Welding*. Baveno, Italy.

5. U.S. Patent 7,538,294 B2.

6. U.S. Dept. of Defense. 2006. *Environmental Security Technology Certification Program (ESTCP), Final Report, Electrospark Deposition for Depot- and Field-Level Component Repair and Replacement of Hard Chromium Plating.*

7. Tang, S. K. 2009. The process fundamentals and parameters of electro-spark deposition. Thesis, University of Waterloo.

8. Gomes, G. F., Vieville, and Durrenberger, L. Dynamic experimental study of spot welders and their influence on weld quality by modal analysis technique. *VIIIth International Seminar in Advances in Resistance Welding*.Baveno, Italy.

9. Mikno, Z. 2014. Analysis of projection welding in relation to the nonparallelism of electrodes. *VIIIth International Seminar in Advances in Resistance Welding*. Baveno, Italy.

10. Gould, J., and Chang, H. 2012. Estimations of compatibility of supercapacitors for use as power sources for resistance welding guns. *Proceedings of the AWS Detroit Section's Sheet Metal Welding Conference XV*, Livonia, Mich.

NIGEL SCOTCHMER (nscotchmer@huysindustries.com) *is president, Huys Industries Ltd., Weston, Ont., Canada.*