PRECISE, HIGH-SPEED, HOT-PLATE WELDING

Drew Jelgerhuis, Bill Reed, Extol Inc., Zeeland, MI

In general, the conventional hot-plate welding process has not kept pace with technology advancements that other widely used plastics joining processes have experienced. Hot-plate welding is known as a robust joining method which can produce strong, leak-tight assemblies in complex geometries, but the lack of sophisticated process control, minimal data acquisition capabilities, and the typical slow cycle times associated with the method have relegated the process to the list of 'least desirable' joining method in the minds of many engineers.

Extol Inc., equipment manufacturer located in Zeeland, MI., has refreshed this dated process with the application of current technology and innovation in the *Rapid Conductor* series, hot-plate welder.

The goals of attaining precision motion control of platen surfaces, heat management, and increased process speed were the primary objectives of the undertaking.

Introduction

A brief review of the traditional hot-plate welding process and related tooling design should prove helpful in the comparison of today's precise, high speed welding technology.

The Process

Hot-plate welding, as the name implies, involves a heated platen with heated tool 'inserts' and two opposing press platens comprised of non-heated tooling. The heated platen is designed to have interchangeable tooling inserts to accommodate the specific welding configuration of the parts being assembled. The temperature of the heated tooling is adjustable; a temperature range for contact hot-plate welding is approximately 350 - 900°F. The press tools are also interchangeable and they are designed to precisely align and support the parts being welded. The machine design may be configured to function in either the horizontal or vertical orientation.

The Process Phases

Hot-plate welding has the following phases.

1. Load – Components are placed in precision, non-heated locating fixturing which insure adequate support and accurate alignment
2. Melt – Both components are automatically positioned to make contact against the heated tooling, the melt displacement is controlled
3. Heat – The components are held at this position (termed 'melt time'), allowing heat to conduct into the material - even though displacement has stopped
4. Open – During this phase the components are removed from the heated tooling, the heated platen is retracted
5. Seal – Components are positioned to bring the semi-molten weld joint surfaces together to form a welded surface
6. Cool – Components are held at a position allowing the welded joint to cool and the re-solidification of the material to occur
7. Unload – Welded assembly is removed from tooling

Making Precise, High-Speed, Hot-Plate Welding a Reality

It requires far more than the addition of servo-driven platens to achieve both precision and speed. Control of the key parameters of force, velocity, distance and heat require advanced hardware implementation *and* significant software sophistication.

The ability to precisely control the key process variables allows for true process optimization and verification, cycle time reduction, and considerable machine set-up simplification. Interesting and helpful features such as heated-platen 'stir' and 'stutter' offer additional control for difficult applications.

Control of Force

True control of the force exerted on the components during the heating and sealing phases of the weld process is critical. To optimize weld strength, precise force control is necessary. Traditional hot-plate weld tooling does not allow for control – or the gauging of, the sealing pressure applied to the components.

Traditional Hot-Plate Weld Tooling

A brief discussion of traditional hot-plate weld tooling is necessary to recognize the control limitations.

Figure 1 depicts a traditional hot-plate weld tool set. This package includes press tooling (shown at top and bottom) and the heated tooling (center). Notice the yellow details; these are rigid, mechanical stops. This is an important characteristic of traditional hot-plate welding.

These stops are used to limit how far each part is displaced into the heated tooling; the same stops on the press tooling are then utilized to control the final seal position. It is necessary in traditional hot-plate welding to design these stops into the tooling to control the travel of the platens due to the limitations of hydraulic or pneumatically controlled machinery.

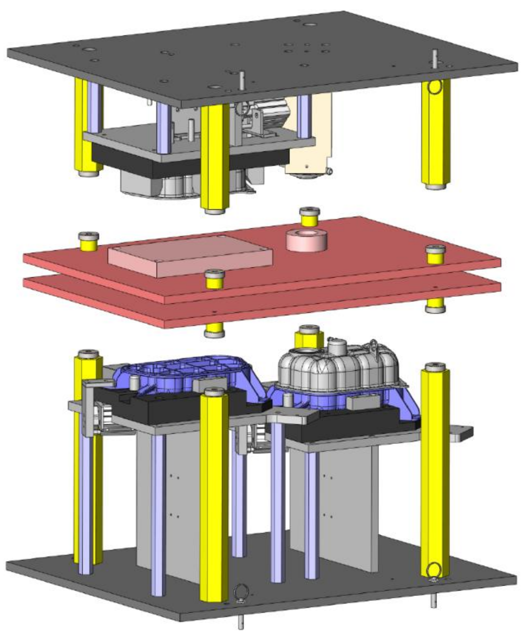

Figure 1. *Traditional hot-plate weld tooling depicting a two-place set assembling two halves of a Tank on the left side and a small Fill Neck detail on the right*

Force vs. Weld Time

Figure 2 is a time/force graph. The grey in the foreground depicts a welder with mechanical stops. The red in the background depicts a *Rapid Conductor* welder - without mechanical stops.

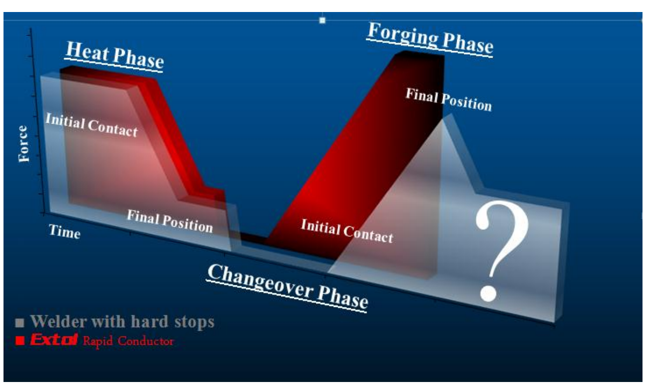

Figure 2. Force vs. Weld Time Graph.

During the initial heat/melt phase, both depicted parts make initial contact with the heated platen with modest force. At the final melt position the force drops off for both machines as both stop advancing the parts into the heated tooling. During the open phase, the force on the components is zero (notice the open time is greatly reduced with the *Rapid Conductor*). During the seal phase the initial low force contact builds in both machine configurations.

Without tool stops the final position is achieved with force that is consistent and measured. With traditional welding the contact of the integrated tool stops determines the final position, the press force is then partially transferred through these stops and subsequently the force applied to the weld joint drops, resulting in the sealing force transmitted to the parts at an unknown value.

This is problematic due to the significance of seal force – as recognized in all welding technologies. This critical controlling parameter must be programmable and measurable to attain optimized and consistent results.

Traditional style mechanical stops have no place in today's demanding manufacturing environment.

Closely related to the relevance of force control is the distinct advantage in controlling velocity of the platen movements, especially during the seal phase. Controlling the rate in which the force is applied and the final seal dimension is achieved has been shown to dramatically improve strength and seal qualities in many applications.

Control of Heat…and the Heated Surface

One detail that hasn't changed in this process revolution is that heat is still required to melt plastic! To achieve consistent weld quality and to reduce cycle time, this heat needs to be presented in an isothermal manner. Without isothermal control the heated tooling may possess temperature variation which could cause extended heat times and potential part damage due to excessive exposure to the proximity of the heated platen.

A robust thermal control system is required. Traditional hot plate welders provide one or two heater zones. At a minimum, Extol implements (5) individually programmable heater zones in the heated platen with as many as (9) zones on the larger welders.

An additional element required for precise hot-plate welding is that of a very rigid and dimensionally stable heated platen. Conventional hot-plate welders typically secure only one edge of the heated platen which results in unmanaged expansion and dimensional inconsistency.

Spatial consistency is the managing of thermal expansion while rigidly securing the heat platen. Spatial consistency allows for tight tolerance part welding and the consistent welding of complex geometry surfaces.

A fully supported heat platen is required to control thermal expansion by designing for growth about the center of the heat plate and to eliminate cantilevering of the heat platen thereby preventing deflection and assuring consistent contact pressure. Extol has implemented a proprietary design using a 2-and-4-way locator slide arrangement which compensates for thermal expansion while maintaining central positioning (see Figure 4).

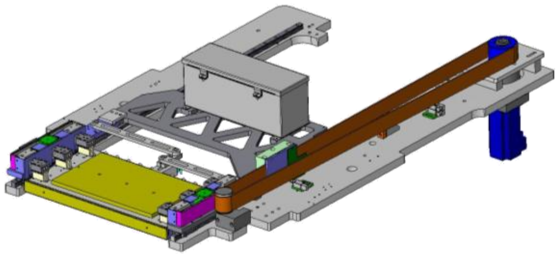

Figure 3. *Rapid Conductor Heat Platen Spatial Compensation Design*

Control of Speed

Having considered force and heat, let's discuss control of speed. Speed is the final ingredient for precise, high-speed, hot-plate welding. It's not just speed, but the right speed at the right position…referring to feed rates, acceleration, and deceleration. As compared to pneumatic or hydraulic actuating methods, the servo motor drive allows for closed loop feedback and control of acceleration and velocities. This control enables the process to be precisely tuned for a given application. Servo controls tied to a graphical user interface provide simple, touch-screen programmable capability of key process variables.

Examples of Features

Tool designs no longer require mechanical stops. This reduces design time, material cost and assembly time. Programmable positioning of the servo controlled platens eliminates the antiquated and tedious process of shimming the stops, too.

An example of the value of the right speed at the right position is when one of the press platens would require traveling a greater distance to the heated tool than the opposing platen. To present the parts to the heated surface at the same time, independent platen control offers unique speed control; in this case two different velocity rates will be used to ultimately present the parts to the heated platen simultaneously.

Additionally, on occasion one part surface may require longer heat/melt time then the opposing, once again independent platen movement will allow for staggered motion to occur while ultimately minimizing open time by coordinating press movements so that the melt times end simultaneously.

Fast, controlled motion of all (3) platens results in a minimal 'open time'. This is significant. Extol strives to keep open time to less than 1-second. Minimal open time is good for cycle time but the true benefits are in minimizing the exposure of the semi-molten weld joint to the environment and the related joint cooling. Minimizing the cooling duration naturally reduces the amount of heat required to push into the joint in anticipation of this cooling. Studies have been conducted with certain resins proving a reduction in weld strength as open time increases.

Fast platen movement speeds are impressive but could be detrimental to the quality of the weld if not equally well controlled for deceleration and velocity transitions. Minimizing open time while controlling seal displacement is critical.

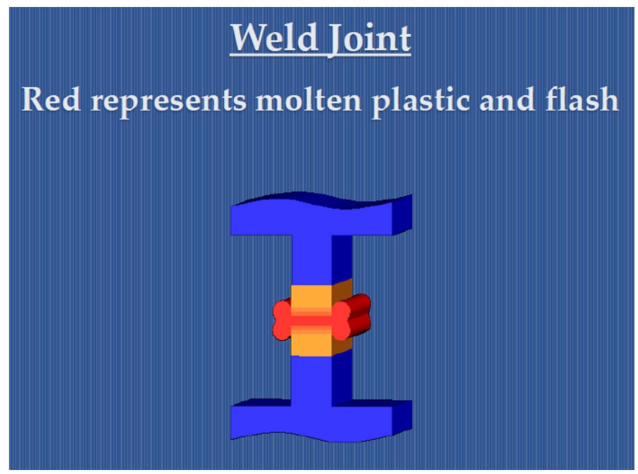

Figure 4.

Without precise control of deceleration at the beginning of the sealing phase the molten film thickness will be displaced to the outside of the weld rib. When this molten film is not retained at the center of the weld a 'colder' weld occurs resulting in weaker joint.

Case Studies

These two case studies describe how precise, high-speed, hot-plate welding can overcome traditional hot plate welding limitations and alternative process liabilities.

Case Study, Polysulfone (PSU) Welding

Polysulfone is very difficult to hot-plate weld; usually the process is not even considered when PSU joining applications are evaluated. Flash control advantages over vibration welding were the primary motivation of this evaluation.

Based on extensive testing it was determined that a seal force *ten times* greater than comparable amorphous polymers is required, and the force must have an even distribution of +/-5 psi across the component surface. The open time of the weld process must be less than 0.8 seconds. The heated tooling must be 700-800^{o} F +/-10^{o}. The results achieved are as follows:

1. Engineered thermal control of +/- 5^{o} F across the heated tool
2. Open time of 0.6 seconds
3. Robust, precision press and heat plate guidance provided uniform and ample seal force
4. Welds resulted in near parent material weld strength (detailed data withheld due to competitive nature)

Success was based on an isothermal platform, a very rigid machine structure, concise programmable set-up capability, and impressive speed.

Case Study, Weld Stacking

Products designed with multiple weld sub-assemblies typically require multiple setups using traditional welding.

This case study involved a pharmaceutical filtration product which required (15) consecutive welds to complete the final assembly. Precise positional control is required due to stack up variation and multi-position feedback.

The flexibility and precision control offered by the Rapid Conductor allows for multiple weld positions within one machine set-up or recipe. Each weld position was precisely programmed to achieve dimensional and force control repeatedly. With the use of consecutive positional control the final assembly was hermetically sealed and well within design tolerance. The cycle time achieved was radically faster than traditional hot-plate welding and did not require multiple setups. In addition to eliminating multiple setups, this method prevented potential contamination and the incurred cost of 'work in process'.

Conclusion

Precise, high-speed, hot-plate welding is a reality. The joining method should be considered as a robust, viable, and technically sound plastics joining process.

[Note: The related topics of heated insert materials, and non-stick, wear resistant coatings advancements, and the acceleration separation relevance in preventing material sticking are matters intentionally not covered in this paper but are certainly worthy of specific review and discussion in a future publication.]

Extol has a 25-year history of plastics joining experience as a custom equipment manufacturer. The servo-driven Rapid Conductor (brand name of Extol servo driven hot-plate welder) is the culmination of over 15-years of designing and manufacturing custom, high-speed hot-plate welders.