Ultrasonic Welding. Complicated joining applications involving semi-crystalline and amorphous thermoplastics can be achieved through controlled build-up of melt. The demanding requirements for quality, velocity and reproducibility are satisfied through variable programming of the weld force and controlling the joining velocity.

Controlled Melt Build-Up

ROBIN MOHR

The so-called caries infiltration technique is a clinically proven treatment method that does not require drilling into a tooth's enamel and is targeted at treating caries at an early stage. Together with scientists from the Charité Berlin and the Kiel University Clinic, Germany, the dental company DMG in Hamburg, Germany, developed a special application aid named Icon for this purpose; it came on the market in March of 2009 **(Fig. 1)**. The therapy is based on a special light-curing resin that is used to fill the enamel lesion and – when activated by blue light – seal the surface. The low-viscosity resin is applied in the gaps between the teeth with the aid of a two-layer, partially perforated film made of polyethylene terephthalate (PET), which is clamped in a holder made of polystyrene (PS) **(Fig. 2)**.

Fig. 1. The Icon applicator is used to treat caries at an early stage

Fig. 2. Application of the gel in the mouth

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Ideal Design Situation

To produce the application aid, a precise joining method for the holder and film was sought to permit correct positioning of the delicate film during the production process without exposure to high temperatures. The already existing perforations in the film presented an additional challenge, since such "injuries" could have an effect on subsequent processing. These represent a disruption of surface, so-called notch effect points at which mechanical vibrations lead to stress peaks. Under certain circumstances, these can lead to undesirable and poorly controlled plasticizing of the resin.

When Herrmann Ultraschall GmbH & Co KG, Karlsbad, Germany, was given the project, the final materials and the design of the weld joints were not yet firmly established. The customer wished to specify these together with the system supplier after the initial welding tests and then design the injection mold accordingly. Such a project presents an ideal design situation for welding via ultrasonics, since the material characteristics and the design of the joint geometry can have a significant effect on the welding results. Because of the small dimensions and the convex and concave shapes, the holder represented a difficult component. Even the slightest dimensional variations in the injection molded parts could pose serious problems. The challenge was to design a suitable weld joint that did not allow melt to escape laterally when welding the holder components while simultaneously clamping the film **(Fig. 3)**. After the first laboratory tests, the holder components were designed such that the originally planned six locating pins, which initially functioned simultaneously as weld joints, ensured an optimal result in the final form of four locating pins and four small thin-walled joints **(Figs. 4 and 5)**. The thin-walled joint

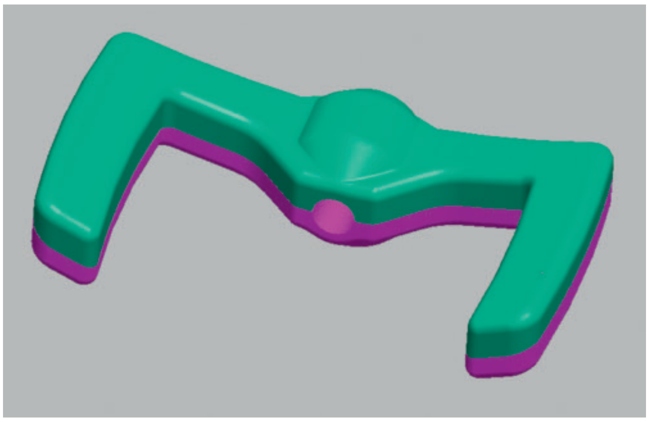

Fig. 3. Holder construction

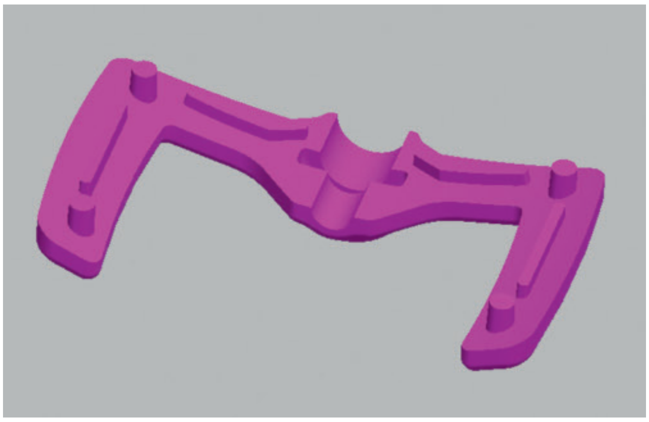

Fig. 4. Locating pins and thin-walled joints (V-joint)

design (V-joint) developed by Herrmann Ultraschall is especially well-suited for small components with thin walls. The energy director has a clearly defined contact surface and facilitates self-locating. High strength and a flawless optical appearance are additional benefits.

Exploiting Different Responses to Temperature

The different responses of semi-crystalline and amorphous thermoplastics to temperature have an effect on the welding results. Thermoplastics are physically related to one another on the basis of more or less highly branched and linear carbon-based chains. The bonding forces are more effective and the resistance to welding increased when the chains are arranged in parallel (crystalline) instead of intertwined (amorphous). Amorphous thermoplastics are hard and rigid. Their specific heat requirement is low, and a small to moderate welding amplitude of between 10 and 25 µm at 35 kHz suffices. Semi-crystalline thermoplastics are softer, tougher and more pliant, and can withstand higher temperatures. A larger specific heat requirement to disrupt the structure means that a larger welding amplitude of between 25 and 35 µm is needed **(Fig. 6)**.

Normally, only similar resins or those with similar melt indices can be welded (for instance: PMMA and PVC). In the present case, the fact that different resin grades are difficult to bond was used to advantage.

While the amorphous holder warms readily and quickly as a result of the mechanical vibrations, the semi-crystalline →

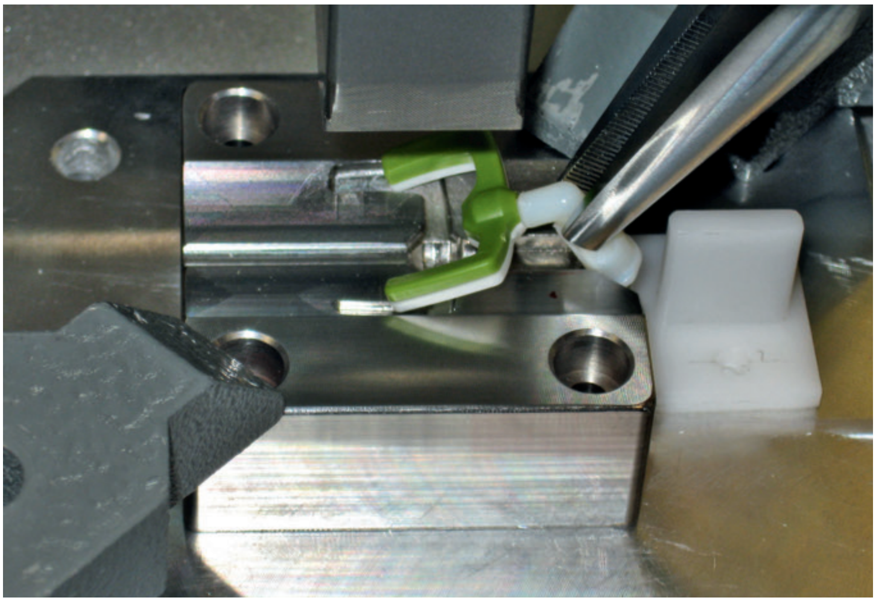

Fig. 5. Initial ultrasonic laboratory tests

Company Profile

DMG Dental-Material Gesellschaft mbH (DMG) develops, produces and markets high-quality dental materials. The family-owned company has over 300 employees, was founded in 1964 by Ernst Mühlbauer and focuses on research and development. Today, DMG sells its products in over 80 countries. Its range of products includes innovative solutions for dentists, laboratories and patients. The DMG product line encompasses molding material, temporary solutions, permanent solutions, prophylactic items, laboratory supplies, application systems and accessories.

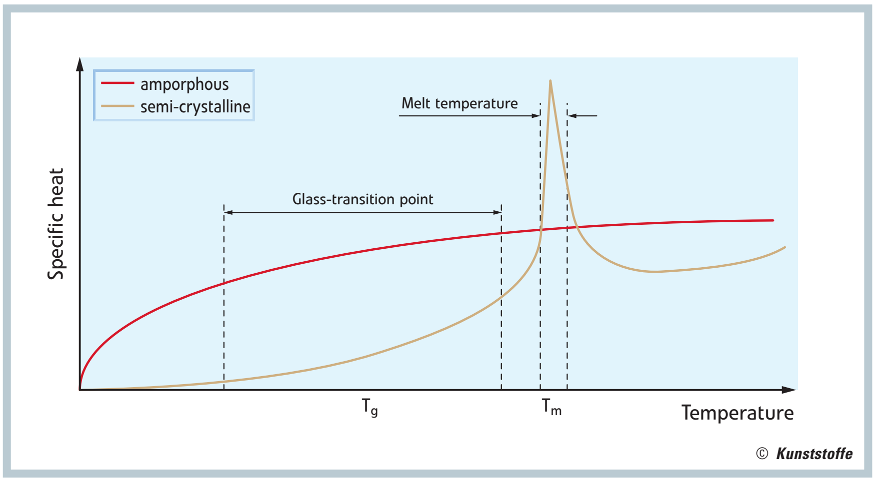

Fig. 6. Response of thermoplastics to temperature

film has a delayed response, which in turn protects it from degrading thermally. More precisely, it was necessary to find the ideal operating point at which the amorphous pin on the holder plasticizes successfully, while only the amorphous components respond adequately in the film and the crystalline components do not. If the energy input exceeds this value, the film melts too much and is destroyed **(Fig. 7)**.

Switching to a Second Weld Force

From the machinery standpoint, the prerequisites for such accuracy are precise determination of the starting position for the ultrasonics (trigger point), controlled melt buildup, and quick and accurate termination:

Trigger point: The approach motion of the sonotrode is observed and the ultrasonics triggered only after the equipment comes to a stop upon contacting the part's surface. Reference point zeroing ensures that dimensional tolerances for the part are equalized.

Melt build-up: The Vario Process in the controls permits programming the weld force in two steps to optimize a linear joining process. The result is controlled melt build-up, a prerequisite for exact reproducibility of the operating point.

Termination: The operating velocity of the generator lies in the µs range. This permits precise termination even with fast welding cycles.

The challenge was to have the sonotrode deliver full output as fast as possible – within the first 20 ms. When welding the Icon parts, the welder switches to a second weld force in the last 7/100 mm (about 20 ms) of the process, just before the end of the weld stroke of 0.22 mm. The melt generated while the first weld force is being applied is compressed by switching to a second, higher weld force. As a consequence, the velocity of the welding operation is retained until the end. This allows the welding time to be shortened. Furthermore, the load on the film from the mechanical vibrations is also reduced, which is important when it comes to avoiding film damage. In addition, the cooling melt is pressed more strongly against the film during the holding period, thus increasing the strength of the weld.

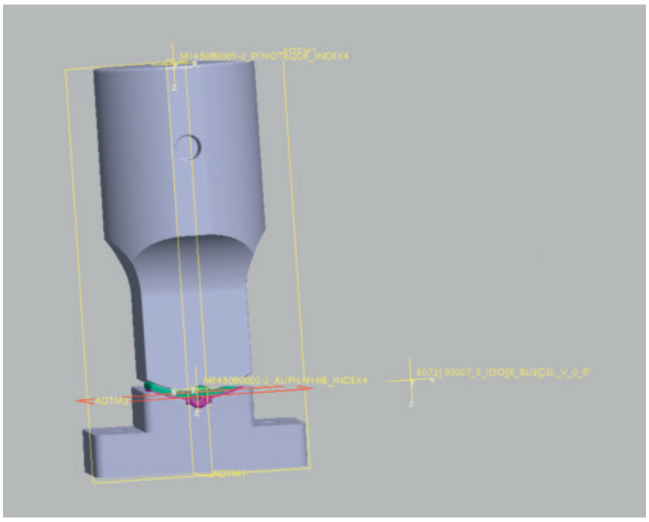

Fig. 7. Sonotrode CAD axis calculation

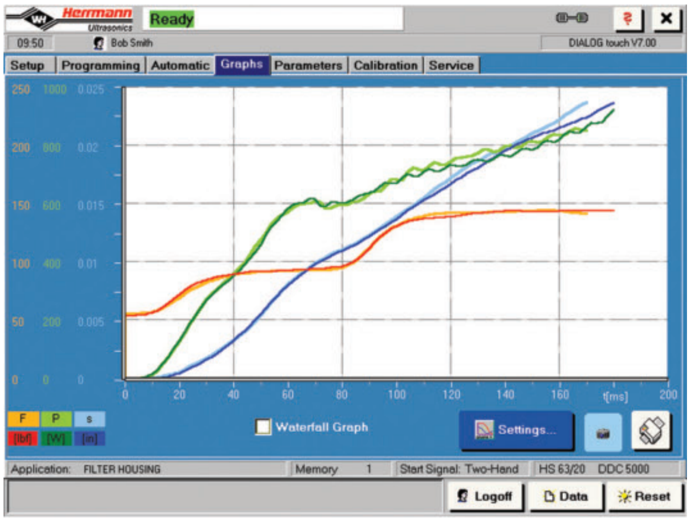

Fig. 8. Screenshot showing joining velocity

Visual Monitoring of the Joining Velocity

Graphical representation of the welding power, joining velocity and weld force permits exact statements about the quality of the joining process **(Fig. 8)**. This avoids unnecessary loads on the parts being welded and guarantees exact reproducibility of the welding process. The linear slope of the curve is ensured only through controlled switchover between the weld forces during the course of welding. A rapid, largely linear increase in the joining velocity (position-time curve) after 20 ms provides a visual representation of a uniform joining process and assures a repeatable result.

Conclusions

With any new development, the primary concern is the functional profile of the component, which the customer establishes on the basis of market requirements. This is followed by the customer's manufacturing requirement profile as well the requirement profile for the actual processing technique. This is where the ultrasonics system supplier comes in and, in an ideal situation, as early as the planning and design phase. The objective is to design components that are suitable for the process, but also to develop a process that is suitable for the components. Modification of components, tooling or machines should, as far as possible, be avoidable or at least planned. ■

THE AUTHOR

DIPL.-ING. (FH) ROBIN MOHR, born in 1966, has been a sales engineer at Herrmann Ultraschall since 2003. Since 2006, he had directed the Technology Center North in Walsrode, Germany;
Robin.Mohr@HerrmannUltraschall.com