This humidification chamber by Gründler medical must be gas- and watertight. As part of a 100 % test, test chambers are put under pressure to test for leaks. This method provides reliable statements regarding tightness in the individual chambers. The breath gas humidification chamber serves to warm and humidify breath gas clinically (all pictures except fig. 6: LPKF)

Join First, Test Later

Laser Welding. Transmission laser welding has become established alongside other joining processes as being an especially precise and hygienic process open to several methods of simultaneous quality monitoring. The following article deals with possibilities for testing subsequent to welding.

FRANK BRUNNECKER

Transmission laser welding is a joining process that offers several approaches for monitoring quality simultaneously. The various aspects of quality assurance are presented in series of three articles. In the first part of the series, the available welding methods and possibilities for error within the process chain ("Laserschweißen im Fokus", ***Kunststoffe*** 10/2011, Document no. KU110886, available only in German) are considered. Among the factors essential to this consideration are variations in materials properties or problems inherited from the manufacture of the joining partners. The absorption rates relevant for transmission laser welding can be reliably confirmed using, e.g., transmission devices.

The second installment in the series of three focused on testing methods within the process ("Welding Processes under Control", ***Kunststoffe*** international, Document no. PE111022, 5/2012). It presented joining path monitoring, pyrometric monitoring and control, burn detection and the new reflection diagnostics. All of these approaches provide robust statements as to weld quality and make them available for uninterrupted tracking & tracing.

This following third part deals with testing subsequent to welding. Sporadic checks of welded parts discover errors that, to some extent, cannot be recognized using the individual online methods presented previously. For instance, blistering (due to overheating or excess water content in the absorbing material) cannot be recognized by joining path monitoring.

The number and frequency of post-process tests then depends on the particular application and on experience with the assembly being processed. Testing requirements can be reduced by combining inline methods. Where uncritical parts are concerned, and materials quality is ensured, experience shows that sporadic, downstream tests are sufficient.

The machine operator is the first one to have an impression of a welded product. The weld seam is clearly visible through many laser-transparent parts, so that error zones are spotted quickly when checked visually upon removal.

Microscopy and Materialography

Significantly more detailed statements can be made, if parts are optically inspected in detail either by microscope or materialography.

When reflected-light microscopy is to be used, an existing part is broken open at the weld seam, and the fracture surface examined and evaluated under a microscope. This method permits the following errors to be recognized quite simply and economically:

- Bonding error: When traces of the one joining partner stick to the other, or to both joining partners, we speak of cohesive fracture. This type of fracture

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Fig. 1. Material that sticks on indicates that this is a cohesive fracture as desired

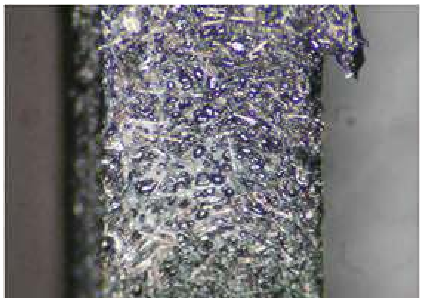

Fig. 2. Under the microscope, bubbles can be seen in the weld seam that occur when water content in the welded plastics is too high

behavior is both desired and ideal, since it indicates that the materials in both joining partners are mixing reliably. However, when no material of the one partner sticks to the other partner, we speak of adhesive fracture behavior, i.e., the strength of the weld seam is less than that of the surrounding material. Such fracture behavior may be desired, but in the great majority of cases, it is not, since it indicates markedly lower strength **(Fig. 1)**.

- Material overheating, excessive water content: When small gas bubbles occur in the fracture zone, they allow two different conclusions regarding causes. Either the process is using too much energy, i.e., the material forms gas bubbles because it has begun to degrade, or else the water content is too high, especially in the case of hydrophilic plastics, such as polyamides. Since water evaporates at markedly lower temperatures than plastics do, blistering takes place.

Both causes of error cannot be detected within the welding process by simple joining path monitoring, but are detected very well by additional pyrometric monitoring **(Fig. 2)**.

Materialography provides additional information, whether in addition to, or instead of reflected-light microscopy. A more precise analysis can be performed by creating a thin section (microtome section). Perpendicular to the weld seam, a section of the material is made that is so thin as to become translucent, thus enabling it to be inspected by both light microscopy and reflected light microscopy.

As can be seen in the figures, given the proper choice of etchants and optical filters, both the weld and the error zones can be recognized by this method **(Figs. 3 to 5)**.

Burst Resistance Testing

One simple and popular method is the burst resistance test. It is suitable for testing parts with weld seams that have a closed, dense volume. Applications include, e.g., housings for various applications in electronics.

A fully welded housing is fitted out with a compressed air valve and subjected to increasing pressure until either the housing or the weld seam fails. The maximum pressure achieved permits conclusions concerning weld seam quality. This method allows us to include a clearly defined value for bursting pressure and the accepted tolerances right in the part drawings.

Burst resistance alone is not a sufficient criterion for providing statements about the welding process, or even regarding weld quality. This test must always be combined with other tests, such as microscopy.

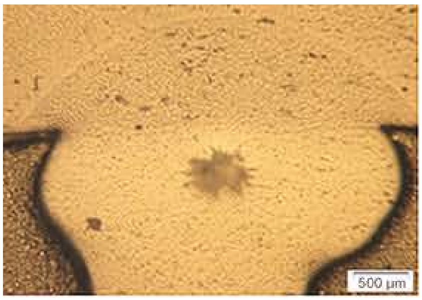

Fig. 3. Errors become visible in the cross-sectional image: The mushroom-shaped melt zone is well formed; however, the material in the center is already overheated and has begun to degrade. The incipient gas channel reduces weld strength

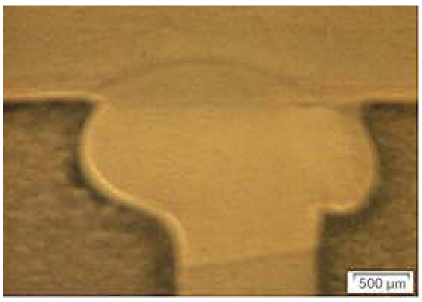

Fig. 4. For comparison: a well-formed weld seam with successful process control

Research in progress indicates that weld seams created within the thermal degradation range of a plastic tend toward higher short-term strengths than do weld seams from lower temperature curves. This behavior inverts wherever generally more important long-term properties are involved. Thus it may even be counterproductive to optimize to the highest bursting pressure possible.

Leakage or Bubble Tests

There is another test that functions non-destructively, but it can be performed only on closed, or at least closable housings. This leakage or bubble test is usually performed prior to a burst resistance test, since preparation of the part is the same for both. In both instances, a compressed air connection is required.

The part to be tested is put under predetermined pressure which varies according to part size and its requirements. A flowmeter registers the after-flowing air quantity which, in an ideal situation, falls to zero. In practice, leakage values usually must remain below minimal values.

Even the smallest leaks can be found by a simple test. If the part is submerged in a water bath, bubbles form to show the position of error zones **(Title photo)**. This can be important, e.g., for readjusting the welding process, or for optimizing the process, as well.

Non-destructive Part Testing

For the testing methods mentioned above, random parts were removed from production and destroyed, or at least used for testing. For applications with the toughest product requirements, this is not possible: Whenever each individual part has to qualify, only non-destructive testing methods are utilized. Such on-going requirements are common especially in the higher risk categories of medical technology.

Examples of the available non-destructive testing methods include x-ray or ultrasonic investigation. Both techniques are, of course, clearly more cost-intensive than the methods described above.

Ultrasonic investigations make use of acoustic microscopy which is based on the same functioning principle as the ultrasonic examinations familiar in medicine: A probe transfers an ultrasonic signal through a coupling medium, gener- →

Fig. 5. Microfluidic components are especially fine, on the one hand, but on the other hand, totally dependent on secure welds

ally water, to the surface being investigated. The sound waves reflected by the material are detected according to their strength, phase and term, and then recombined with an image of the internal structures. Error zones in a weld seam, as well as bubbles in the area of the weld can be reliably detected by ultrasonic investigation **(Fig. 6)**.

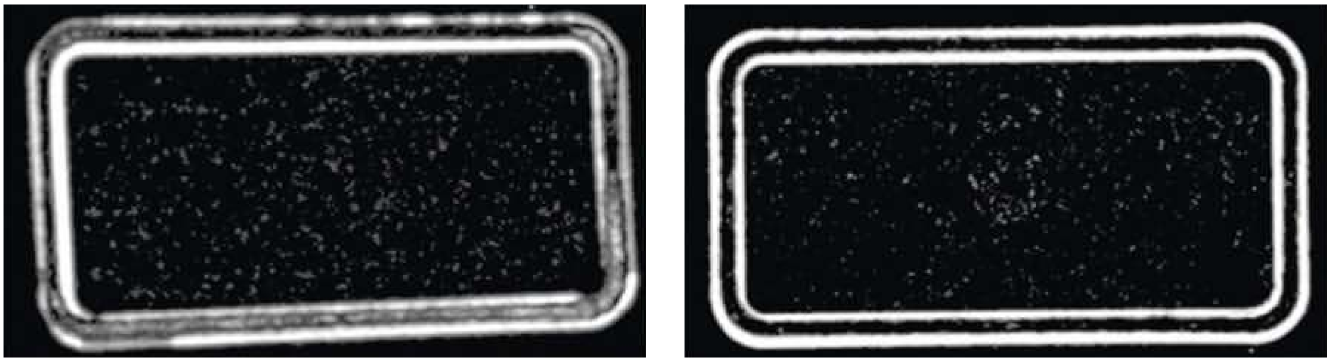

Fig. 6. The image on the left clearly shows bonding error and blistering at the weld seam. The image on the right shows an error-free welded part.
(photo: Continental Teves AG)

X-ray analysis and/or x-ray computed tomography (CT scan) function non-destructively. The part is scanned by x-rays, resulting in a cross-sectional image of the scanned body. Depending on configuration of the device, 2-D or 3-D images are detected.

Industrial solutions first evaluate a good part and use subsequent measurements of it as a reference in test logs, or in schematic presentations with color-coded accentuation of the differences, as well. Depending on configuration, not only its weld seam is tested; also detected are any inhomogeneities in the base material, deviations from part geometry or any changes in materials properties.

Conclusions

Transmission laser welding has become established alongside other joining processes as an especially precise and hygienic process. This three-part series dealing with quality shows that the laser can also claim clear advantages where safety is involved. Especially the inline methods presented in the second part render complicated subsequent testing methods superfluous, or can at least minimize the number of samples that have to be tested.

Transmission laser welding is located close to the end of the production chain. The laser is so flexible that can be utilized to compensate tolerances in the pre-products. For welding to the limiting stop, the laser remains active until a defined joining path has been reached. This compensates geometry variations to some extent. A suitable combination of inline testing methods ensures a high level of safety even where critical parts are involved. Combined joining path and pyrometer monitoring can detect nearly all the error images in the welding process described here and alert the operator to any deviations. If the testing methods are properly integrated into the laser welding system, cycle time is not significantly lengthened.

For the last step, we can state as a rule that intelligently conceived inline monitoring markedly reduces the effort and expense of any subsequent random tests. In many cases, they can be done without. Transmission laser welding then demonstrates its technological advantages while reducing the overall cost for each part. ■

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