Magazine for Plastics 9/2015

Kunststoffe international

POLYAMIDES

Preventing Contact Corrosion in Flame Retarded Polyamides for Electrical and Electronics

page 68

SPECIAL

24th Fakuma – Preliminary Reports

page 11

JOINING TECHNOLOGY

Ultrasonic Staking for Joining Plastics and Dissimilar Materials

page 54

www.kunststoffe-international.com
HANSER

Staking by Ultrasound

Strong Joints in Short Cycle Times

A novel version of ultrasonic staking for joining plastics and dissimilar materials utilizes a tubular rivet that it shapes into a form-fitting bead. This new process, termed ultrasonic compressive staking, is characterized by short joining times and high breaking tension.

The increasingly common substitution for classic metal applications by plastics has resulted in the increased use of hybrid material constructions (e.g. metal-plastic, thermoplastic-thermoset or incompatible thermoplastics) and multi-component systems. These fields of application entail constantly toughening product requirements in terms of mechanical and optical properties and, therefore, require new processing strategies that enable high bonding strength together with short cycle times.

Staking processes have become established as methods for joining components made from thermoplastics with components made from dissimilar materials where coalesced joints cannot be achieved by welding. During the staking process, the protruding head or dome of the stud is warmed, plasticized and shaped by applying pressure to it, so that a form-fitting bond forms between the joined parts. Classic staking methods often exhibit disadvantages due to partially insufficient bonding between the staked head and shank (**Fig. 1**). This can have negative effects on strength, optics and function [1]. Attempts to improve the situation often result in a drastic lengthening of the joining time.

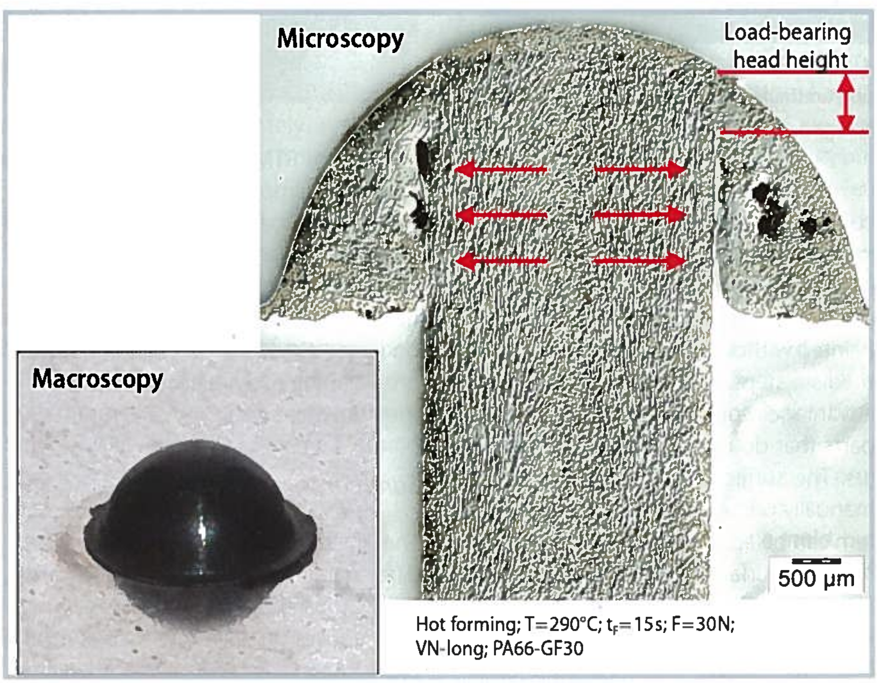

Fig. 1. Partially inadequate bonding of the staked head to the shank can be a problem with classic staking (figures: KT-Chemnitz)

A New Approach – Ultrasonic Compressive Staking

For this reason, Herrmann Ultraschall GmbH & Co. KG of Karlsbad, Germany, and the Chair for Plastics of the Technische Universität of Chemnitz, Germany, have worked together to develop ultrasonic compressive staking for plastics parts. This novel process replaces the classic process of shaping the stud. Instead, it utilizes a semi-tubular stud with a bore whose diameter varies with the stud diameter, the material and the thickness of the part to be staked.

In the first processing step, the tubular stud is plasticized internally by ultrasound from a suitably fitting sonotrode tip, thereby creating a melt cushion. In a second step, the partially warmed stud is compressed by the sonotrode shoulder. The stud bead thus created forms a high-quality form fit bond (**Fig. 2**). Depending on the material involved, compressing can be performed with or without applying ultrasound.

Sophisticated Plastics in Tests with Multifarious Parameters

The investigations primarily focused on PA66-GF30 (manufacturer: BASF SE, Ludwigshafen, Germany), a construction material used industrially for numerous different applications. The low melt viscosity and high melting temperature make severe demands on the staking process. Additional investigations were positively undertaken using the materials ABS-PC, POM, PBT-GF30, PC-GF20 and PMMA in order to attest the applicability of the process to a wide range of applications.

The investigations were performed on a Herrmann Ultraschall HiQ Dialog SpeedControl 1200 ultrasonic welding machine (system frequency 35 kHz). The machine has a digital ultrasound generator for variable amplitude control and the HMC pneumatic drive concept provides precise joining force control, thus combing the advantages of pneumatics with the dynamics of an electric drive. Consequently, the machine is characterized by precise recording and evaluation of relevant process parameters, such as amplitude, joining path and joining force curve.

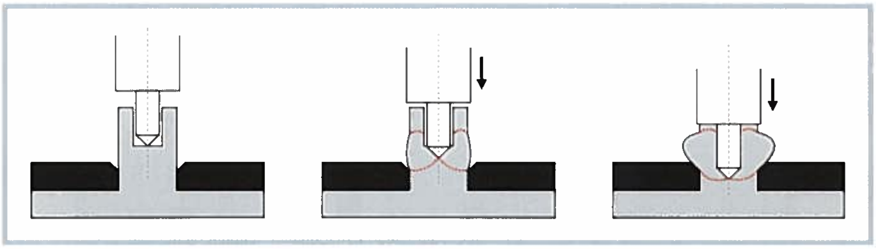

Fig. 2. New method of ultrasonic compressive staking: warming (left), plastification (center), shaping by compressing (right)

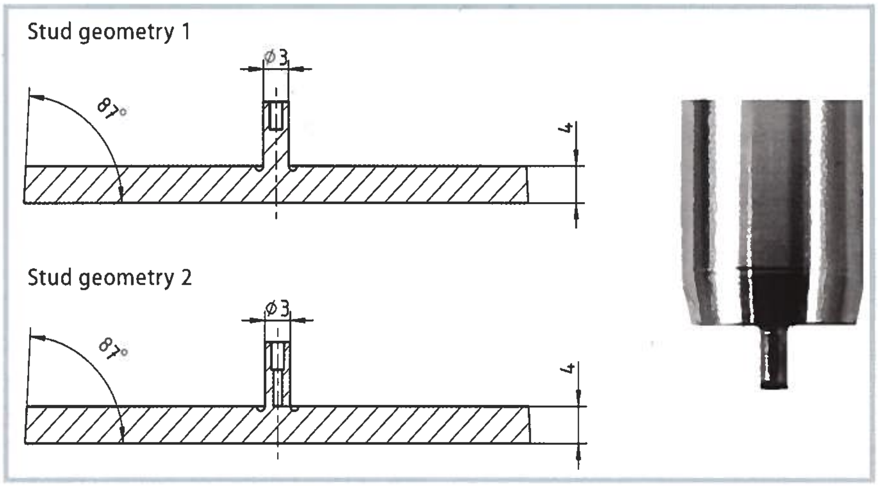

Fig. 3. Newly developed stud geometries and the sonotrode adapted to them

New Geometries of the Staking Stud and Sonotrode

The experimental investigations were based on a specimen for which variable tubular geometries could be created during injection molding with interchangeable insets in the mold. A rivet with a 3 mm defined outer diameter and variable internal geometry sits on a base body measuring 60 x 60 x 4 mm³. Geometry 1 is a partially hollow stud whose bore ends just above the joining partner (**Fig. 3**). Geometry 2 has a stepped bore that narrows down to the rivet bottom (**Fig. 3**). The joining partner used was a 3 mm thick steel u-shaped profile with an edge length of 30 mm. As schematically shown in **Figure 3**, the sonotrodes are equipped with a spike on the bottom that is designed and configured to fit into the bore in the tubular rivet.

Optical and Mechanical Assessment of Staking Quality

The performed analyses focused on determining the particular fracture force in tensile tests at a testing speed of 5 mm/min. Microsections were used to assess the external and internal formation of the stud bead via macroscopy and microscopy.

The investigations showed that the join quality depends strongly on the design of the tubular stud. In **Figures 4 and 5** it can be seen that both geometries achieved maximum fracture strength of approx. 460 N. Difference showed up in the micro- and macroscopic properties of the rivet bead and in the processing window. The fracture strength of geometry 1 determined in the uniaxial tensile test indicated dependence on joining force during parameter optimization. Loss of fracture strength was recorded with rising joining force at constant amplitude (**Fig. 4**). This behavior showed up across the entire available amplitude window.

As amplitude and joining force rose, the joining time required to create a bond fell due to the higher specific energy input.

During parameter optimization, geometry 1 often exhibited material budding from the bead (**Fig. 6, left**) with negative effect on optic properties and resulting in lower strength. The melt pressure developing within the tubular »

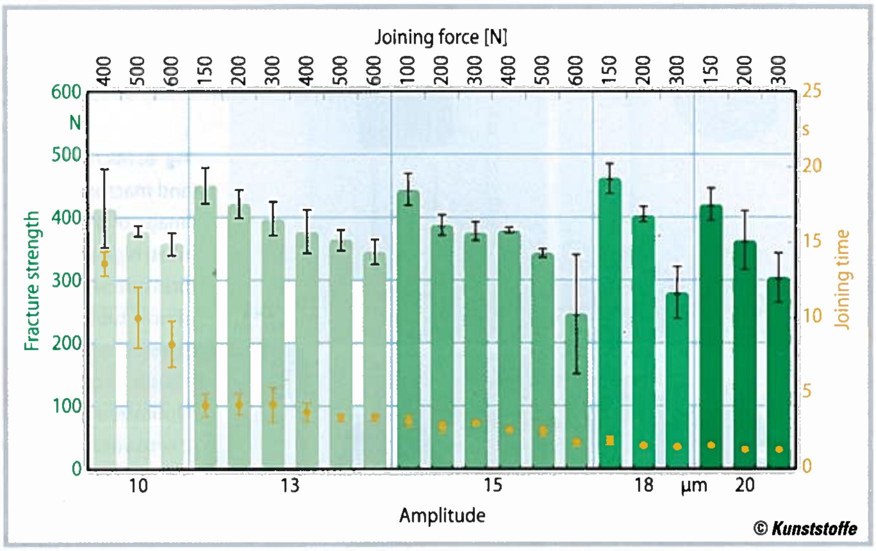

Fig. 4. Parameter optimization for ultrasonic compressive staking to maximize fracture strength for geometry 1 (semi-tubular stud)

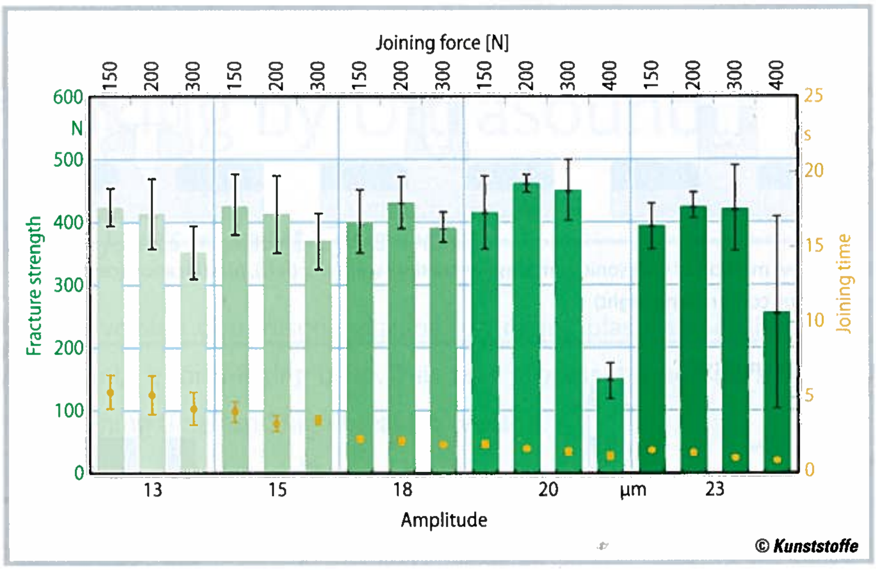

Fig. 5. Parameter optimization for ultrasonic compressive staking to maximize fracture strength for geometry 2 (semi-tubular rivet with staggered bore)

rivet due to material displacement by the sonotrode tip has a critical effect that leads to budding especially when low viscosity materials, such as PA66, are used. Due to the higher viscosity of the base material, reshaping can proceed without budding only when low amplitudes and high joining forces (e.g. amplitude 10 µm, joining force 600 N, **viz. Fig. 4**) are used. The higher percentage of cold reshaping, however, can cause microcracking in the compressed bead. In addition, the resulting joining times rise sharply under these parametric combinations.

Further optimization of the tubular stud was achieved by a staggered bore inside the stud, thus creating additional volume for the material displaced by the sonotrode tip, thereby preventing budding from the bead (**Fig. 6, right**).

Since the load-bearing cross-section of the tubular stud remains unchanged, the new internal shape has no negative influence on the achievable fracture strengths. The new geometry 2 enabled optically perfect bead shaping within a larger processing window. For PA66-GF30, the optimum was reached at an amplitude of 20 µm, a joining force of 300 N, as well as 460 N achieved fracture force. The joining time required lay within a very economical range at 1.5 s (**Fig. 5**).

Comparison with Other Staking Processes

The results show that the ultrasonic compressive staking method can fulfill high technological and economical requirements.

Figure 7 shows the maximum fracture strain achieved with ultrasonic compressing compared to that of three ther-

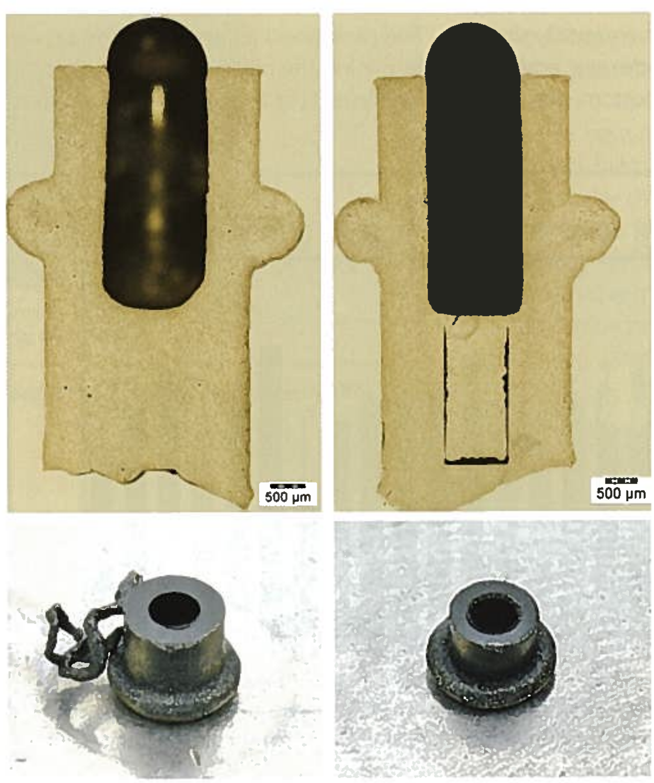

Fig. 6. Microscopic and macroscopic image of the sample rivet: high melt pressure within the simple tubular stud (geometry 1 / left) causes budding. Optimized geometry 2 with volume adapted for resulting melt avoids budding and results in an optimum bead shape

The Authors

Dipl.-Ing. Thomas Fischer is Head of Application Development at Herrmann Ultraschalltechnik GmbH & Co.KG in Karlsbad, Germany.
Dipl.-Ing. Eric Brückner is employed by the Chair for Plastics in the field of joining technology at the Institute of Conveyor Technology and Plastics (IFK) of the Technische Universität Chemnitz, Germany.
Prof. Dr.-Ing. Michael Gehde heads the Chair for Plastics at the Institute of Conveyor Technology and Plastics (IFK) of the Technische Universität Chemnitz.

Acknowledgment:
We would like to thank the Forschungsnetzwerk Mittelstand AiF (ZIM) for their support and friendly assistance with the basic project.

Service

References & Digital Version
- You can find the list of references and a PDF file of the article at ***www.kunststoffe-international.com/1092728***

German Version
- Read the German version of the article in our magazine ***Kunststoffe*** or at ***www.kunststoffe.de***

mal staking methods (hot forming, hot stamp staking, hot air staking), as well as classic ultrasonic melt staking. Two DVS-standard solid stud geometries with various size heads, one DVS-standard tubular stud geometry, and the newly developed tubular geometry developed for ultrasonic compressive staking were considered.

When assessed for mechanical properties, the geometry of the new ultrasonic compressive staking process has to be considered as a tubular stud. The process achieves a maximum strength of 87 ± 3 MPa. To be sure, this lies below the strength achieved for long DVS solid rivet geometries under hot forming. However, when compared directly as applied, it lies clearly above the strength of the DVS tubular stud geometry achieved by hot stamp staking with a maximum of 63 ± 5 MPa.

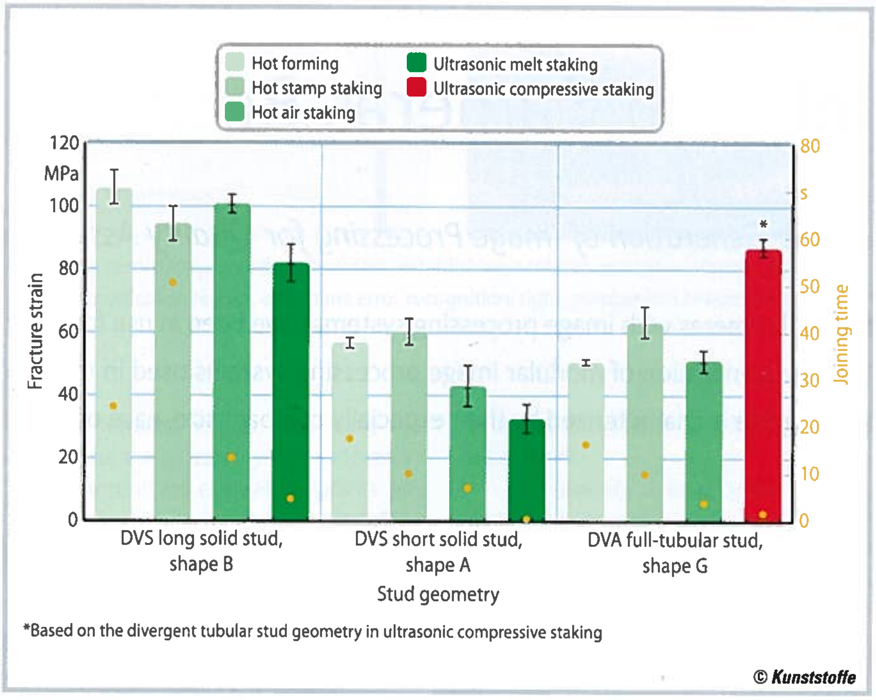

Fig. 7. Strength/fracture strain. Comparison between the staking methods common in the market and ultrasonic compressive staking shows high fracture forces along with short joining times

Advantages and Limits

Ultrasonic compressive staking exhibits clear advantages in point of joining time when compared with thermal staking methods. In the case at hand, this amounts to 1.6 s, whereby an additional process holding time of 1 s has to be considered. Thermal staking methods typically require clearly longer joining times, 10 s to 20 s, without even taking the required stamp warm-up time and the recommended cooling cycles into consideration.

The design limits of the new process currently lie in the minimum stud diameter of 3 mm. Plastification in the center of the tubular stud requires sufficient material volume and/or adequate diameter. Reduction of the remaining supernatant above the rivet bead is the object of current investigations. At the moment, this remains a disadvantage compared with classic DVS rivet geometries that exhibit lower fracture forces, on the one hand, but also require less space.

Conclusion

Ultrasonic compressive staking is relevant for a wide range of materials and enables bonding between new types of sophisticated materials combinations. The know-how here lies in rivet and sonotrode design, whereby the stud has a tubular shape and is characterized by a variable bore depth varying with and adapted to the application. Budding can be eliminated via the bore depth. The finely adjustable parameterization inherent in ultrasound enables targeted energy input as well as adaptation to part tolerances, such as can occur with multiple studs. With this innovative shape of workpiece and tool, the ultrasonic input is almost entirely uncoupled, thereby sparing sensitive parts. In addition to high strengths, the joining times of maximum 3 s for the staking process including holding time lie clearly below the double-digit seconds required by other thermal staking methods. Practical opportunities for using the new method could include staking PCBs or boards, magnets, sheet materials, etc. ■