In: ANTEC® 2013 - Proceedings of the Technical Conference & Exhibition, Cincinnati, Ohio, USA April 22-24, 2013. Society of Plastics Engineers, 2013, S. 738-742, EISBN: 978-1-59124-974-0

DEVELOPMENT OF A RADIAN FRICTION WELDING MACHINE USING THE CIRCULAR PROCESS WITH LIMITED ROTATIONAL MOTION

Hans-Peter Heim, Stefan Jarka, Willi Fischer
University of Kassel

Abstract

The processing-technological limitations of components which can not be continuously rotated, either due to their length or marginal protrusions, make the realization of several potential applications using rotation welding unthinkable. The difficulties that arise while generating a high quality weld and are caused by large component tolerances and component warping are known.

In order to extend the potential of friction welding, it is necessary to develop a new welding technology. In cooperation with Fischer Kunststoff-Schweißtechnik GmbH, such an innovative friction welding method known as radian welding or ROV (Rotatives Vibrationsschweißen) has now been developed. It functions according to the circular process with limited rotational motion. The main task of the welding equipment manufacturer in this research project was to design a welding machine that operates in line with the newly designed process. After documenting the basic engineering principles of this process, potential applications for the plastics processing industry will then be elaborated. Apart from extending the ability to weld components with a rotationally symmetrical weld, the new technology creates additional benefits for processing and the properties of the welded component in terms of the strength and tightness of the weld line and the quality of the welded parts.

Introduction

Welding processes are frequently classified according to the method of heat application – primarily conduction, convection or friction [1]. The welding process examined in this paper can be categorised as a friction welding process. The axially rotating motion on a limited circular path as is required by the new welding process means that the parts to be joined must have rotationally symmetrical weld geometry. The frictional motion and frictional velocity curve are shown in Fig. 1.

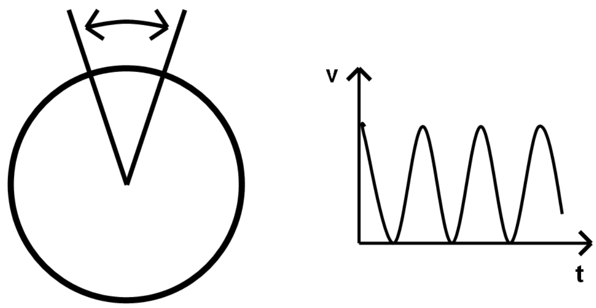

Figure 1: Frictional motion and frictional velocity curve of the radian welding process

Conventional practical applications include connectors, cables, wires tanks and similar products. Thus far, such friction welds were only possible by means of spin welding. Accordingly, possible applications for the new process might be connections previously produced by spin welding or components that were considered unweldable, because the parts could not be rotated. When employing normal spin welding, a constant rotational motion of one of the parts is required. In practice, the possibility of using spin welding is frequently excluded, because the parts to be welded feature side connections or fully assembled add-on parts. Figure 2 shows examples of semi-finished products, which can only be optimally joined by employing the new welding process.

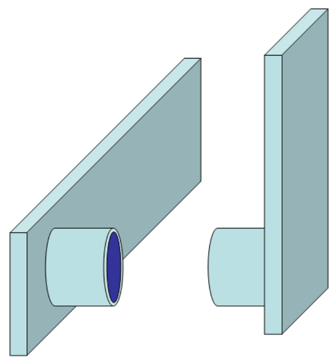

Figure 2: Examples of semi-finished products optimally suited for ROV

Further disadvantages of conventional spin welding result from the continuous rotating movement and, in correlation with this, the expelling of the molten plastic. Wall thickness tolerances and warpage after injection moulding often intensify the effect. This can lead to a particularly thin melt layer, resulting in a loss of quality and a comparatively low level of leak tightness [2]. In the welding process examined here, the polymer is melted in a stationary situation and any uneven sections in the weld area are balanced out. A thicker melt layer is expected.

Objectives

In order to be able to implement the new process, a pilot machine must be developed first. It must be capable of generating the vibrating motion described in Fig. 1 and must also comply with all other requirements of a welding machine: control of the vibrating motion (frequency and radian), pressure and time, and also the rigidity of the machine set-up. How the specified kinematics can best be implemented will be studied by examining various drive and transmission techniques.

The study will also examine the properties of the welds produced using the new processing method. The aim is to investigate if the new welding technology can actually produce the expected/desired benefits and under what conditions the process can be optimally employed. Therefore, it is necessary to analyse the weldability of various amorphous and semi-crystalline thermoplastics, which also contain fillers/ filling materials.

First, it is obligatory to define/determine a suitable geometry for the test specimen. In this case, the required geometry for successful radian welding is an axial symmetrical weld geometry. In addition, it must be possible to apply the necessary measuring techniques to the specimen and to perform mechanical and microscopic analyses on them.

After the completion of the welding tests and an evaluation of the acquired results, the focus of this paper will turn to the optimisation of processing. In turn, this will enable the definition of the basic engineering principles of the new radian friction welding process.

Method

A number of different methods will be employed, in order to develop the most suitable equipment for radian welding. The first type of machine encompasses a direct servo motor drive without a transmission system. A transmission technology was then developed to divert the continuous rotating motion of the electric motor into the limited radian motion. In order to do so, a circular system that was previously tested at Fischer Schweißtechnik was used. The system contains an additional rotatable shaft that is positioned on the drive shaft. The pre-defined amount of rotations leads to an intentional eccentric motion compared to the inner shaft. Fig. 3 shows a model of the circular principle. The continuous, gyrating movement produced can be diverted by a guide system with guide rails into an oscillating motion and, subsequently, via a belt transmission into a radian motion for the welding process. As an alternative to the belt gear transmission system, this study also looked at a belt-free transmission system, in which the transmission with guide rails can be dispensed of. In this case, conversion of the gyrating movement from the circular arrangement is performed by lever arm mechanisms and spring bars [3].

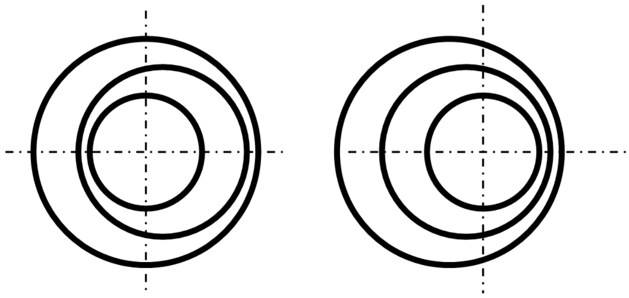

Figure 3: Model of the circular system

Instrumented tests are a necessity for the documentation of the parameters of the welding process. Measurements are taken of the frequency and the radian of the vibrational motion, the welding distance and welding pressure against time, and the temperature on the weld.

Tensile tests and bursting pressure tests were performed to evaluate the properties of the welded specimen. Furthermore, microscopic studies of the weld line were carried out to obtain information of the weld geometry and the thickness of the melt layer.

The results of the tests carried out with the new welding method are to be recorded in suitable literature such as the guidelines of the German Welding Society, DVS. This has also been done in the past with established welding processes, in order to encourage greater use of the process, in particular by small companies [4]. The content of these guidelines should cover not only the procedure for utilising this method, but also recommendations for processing the examined thermoplastics.

Results

During the development of the machine technology, it became evident that a servo motor cannot comply with the requirements of the vibrational motion without a transmission system with a direct link to the welding tool. It can only reach a frequency below 50 Hz. Fig. 4 shows the first type of radian welding machine. Further developments in this area are planned.

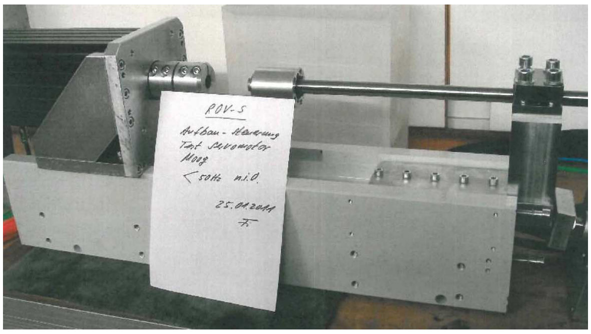

Figure 4: Radian welding machine with direct servo motor, no transmission system is required for the radian motion [Fischer ST]

The circular arrangement proved to be very suitable in the other machine variants. It can achieve stopping times of 20 ms for the vibrational motion ranging from e.g. 160 to 0 Hz. Depending on the rpm, a servo motor requires 100-500 ms. The stopping behaviour that is superior to the rotational welding method (Figure 5) leads to an increased weld strength at the end of the welding process [3].

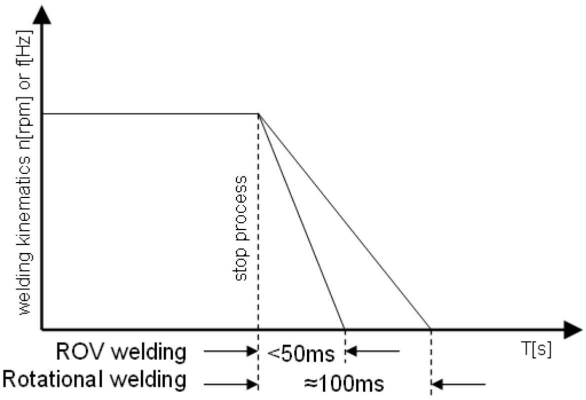

Figure 5: Course of motion and stopping time in comparison to rotation- and ROV-welding

Another advantage of the circular system is the precise stopping at the zero position. Both factors prevent distortion of the melt in the weld area as it begins to freeze.

The projected welding machine with a belt transmission initially proved to be suitable as it provided an adequate frequency for the welding operation. However, losses later occurred through stretching of the synchronous belts. Furthermore, friction within the guide rails resulted in excessive heat generation.

The further developed transmission variant, in which synchronous belts and guide rails were left out, displayed greater rigidity and non-critical heat generation when employed for a longer period of time. Furthermore, it was possible to work with higher frequencies than in the previous machine variants. The welding process and the required process parameters were reliably implemented. An attachable transmission also allows welds of small weld diameters of up to 6mm.

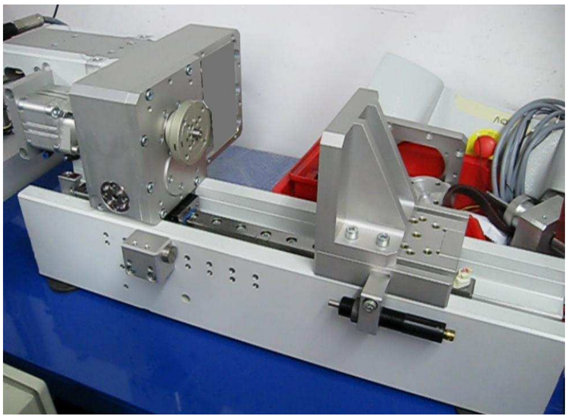

Figure 6: Radian welding machine with circular arrangement and lever arm mechanism [Fischer ST]

For the weld tests, an injection moulding tool with an interchangeable cavity was produced to enable the production of three different samples. The specimen geometries, as shown in Fig. 7, enable necessary measurements during welding and also allow tensile tests, bursting pressure tests and microscopic analyses to be carried out in the weld zones.

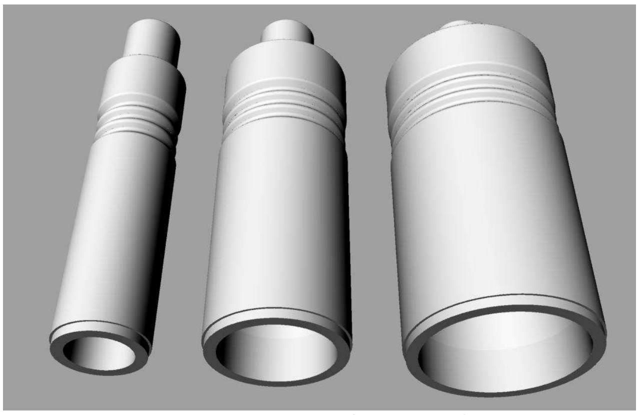

Figure 7: Specimen geometries of the semi-finished products for the welding tests

During the subsequent course of the project, test series with different materials are to be carried out and evaluated. This will be the task of the welding machine manufacturer and later, for a limited period of time, that of the Institute at the University of Kassel. This will enable findings concerning the processing parameters in regards of the properties of the welded specimen.

First welding attempts revealed not only feasibility, but also the potential of the new processing method. Despite the complex gear drive for the redirection of the eccentric motion into an arc motion, a high stiffness and positioning precision was determined for the prototype machine.

Mechanical tests of the welded specimens of polypropylene, polycarbonate, unreinforced and glass fiber reinforced polyamide show good mechanical properties in tensile tests. A comparison to the yield strength of the basic material was done. Figure 8 shows results of the tensile tests of the samples with 40mm diameter with the four materials, welded with different welding pressure (process setup 1 < process setup 2 < process setup 3 < process setup 4).

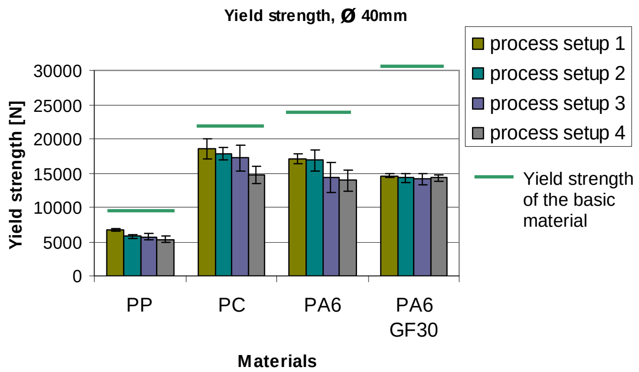

Figure 8: Results of the tensile tests of the samples with 40mm diameter

Burst pressure tests show the component behavior against media pressure, as is required in many applications. Figure 9 shows results of the burst pressure tests of the samples with 30mm diameter with the four materials, also welded with different welding pressure.

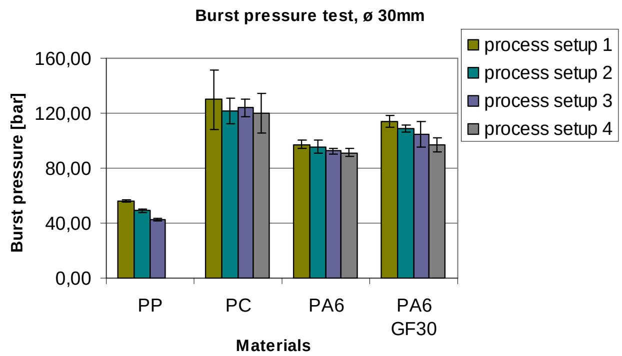

Figure 9: Results of the burst pressure tests of the samples with 30mm diameter

Using the microscopy the quality of the welds was investigated. Figure 10 shows a polypropylene sample with 20mm diameter and a wall thickness of 1mm and produced at low welding pressure. It is a light microscope image of the weld with direct reflected light. Visible is a clean connection with uniform weld thickness.

Figure 10: Light microscope image of a polypropylene sample with 20mm diameter and a wall thickness of 1mm

Prospects

A comparative study of the weld properties using alternative friction welding technologies should be made to illustrate the potential of the new welding process.

In a further step, the principles of the new welding process will be documented in suitable literature in accordance with the DVS guidelines.

This research project and cooperation with the welding machine manufacturer aims to establish the new radian welding process, so as to gain customer interest and enable a utilisation of process advantages in the industry.

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