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Development of a flexible polymer joining center capable of performing multiple joining processes using different methods in a single cycle

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Abstract

Goal of this research and innovation project is the implementation of a flexible polymer joining center as a prototype machine integrating different friction welding methods. This prototype joining cell combines (a) flexibility by being capable of performing joining processes in any order in a single flow with (b) modularity by integrating unified interfaces for exchanging joining modules, and (c) scalability by offering a wide range of setups for smaller to larger work pieces. Corresponding interfaces to up- and downstream processes enable implementation in fully automated environments.

This paper will give a brief overview of the introduced technology and its current project status, and present results from first welding experiments, mainly investigating reproducibility of welding results, and give an indication of overall welding quality potential.

Introduction

The constant trend towards lean and flexible production systems leads to a rising demand for flexible while still highly automated and integrated polymer joining cells. This demand is reinforced by a rising rate of polymers being used in automotive engineering with weight saving measures being one of the main drivers for this boost. Polymer processing additionally offers other possibilities for construction and design, function integration continuing to be an important trend these days. This leads to more complex part geometries which entails that they often have more than one joint type. With only one machine per method this implies moving parts from machine to machine, losing precious time on the way and having much higher capital costs. With these thoughts on faster and leaner joining in mind the SME *Fischer Kunststoff-Schweißtechnik GmbH* came up with the idea of a joining center that would be able to perform multiple different joining tasks one after another fully automated on one single joining center without need for manual intervention or moving parts to another welding station. For the past year Fischer has worked together with the Polymer Technology Group of the University of Kassel's Materials Sciences Institute in order to achieve market readiness for a modular, flexible joining center with exchangeable welding modules, 2D CNC capabilities, and material handling support. To ensure competitiveness it is expected that the joining center produces a sufficient level of reproducibility with according weld seam quality that has to be on par with that of conventional machines.

The Technology

The flexible joining cell prototype's base is a CNC machine which was entirely decommissioned and overhauled by Fischer and afterwards fitted with new actuators and a novel interface system able to accommodate different exchangeable joining modules, mainly aimed at thermoplastic friction welding applications.

As of now a prototype has been assembled with basic functionality including z-axis actuation enabling pressure- and distance-controlled welding processes. As the polymer welding modules are significantly lighter (ca. -100 kg) than the original CNC module the counterweight of the old machine was disconnected in favor of a setup with counter-pressure cylinder and pressure reduction valve for reduced friction allowing higher control precision.

Three to four controllers for up to eight friction welding modules are included in the current project scope for spin, linear vibration, orbital, and radian welding with different performance measures in order to cover various part sizes and different materials (as metal friction welding shall also be considered). These modules can be easily exchanged according to current production needs as they all use the same interface to the machine base. The machine table's x- and y-axes are to be actuated so that any number of joints located within the confines of the center's table can be reached. The welding module itself is displaceable in z-direction in order to approach joining locations of different height on 3D parts, and to perform the necessary precise displacement for the joining process itself. Figure 1 shows the flexible joining center prototype (left) and one of its friction welding modules in detail (right) during control precision testing with the pressure sensor visible below the welding module.

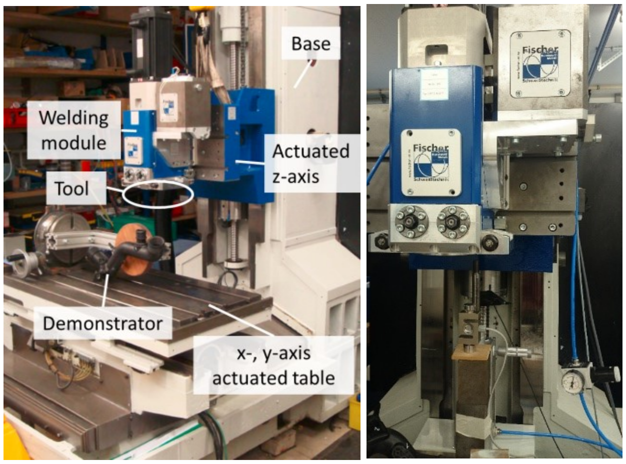

Figure 1. Flexible joining center prototype (left), friction welding module in detail (right).

As of now, high control precision is given for joining forces between 0.8 and 20kN.

Experiments

To examine the prototype's joining reproducibility and indicate overall weld seam quality, specimen of currently two common thermoplastics were friction welded by the advantageous circular welding process [1] by the prototype and subsequently tested at University facilities for tensile strength, burst pressure, and weld morphology analysis utilizing light microscopy.

The materials utilized for the welding experiments are one polypropylene homopolymer for injection molding with the product name Sabic PP 575P, and a polyamide (PA) 6.6, also an injection molding product with 30% fiber glass reinforcement from Albis with the name ALTECH PA66 A 2030/310 GF30 IM.

The specimen are of a geometry that has been developed at the University of Kassel for welding experiments with high suitability for tensile, burst pressure, and optical testing (microscopy) and is based on semi-finished products, see figure 2 [2].

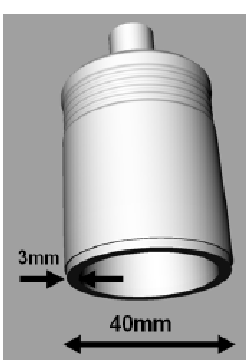

Figure 2. Specimen geometry, based on a semi-finished product.

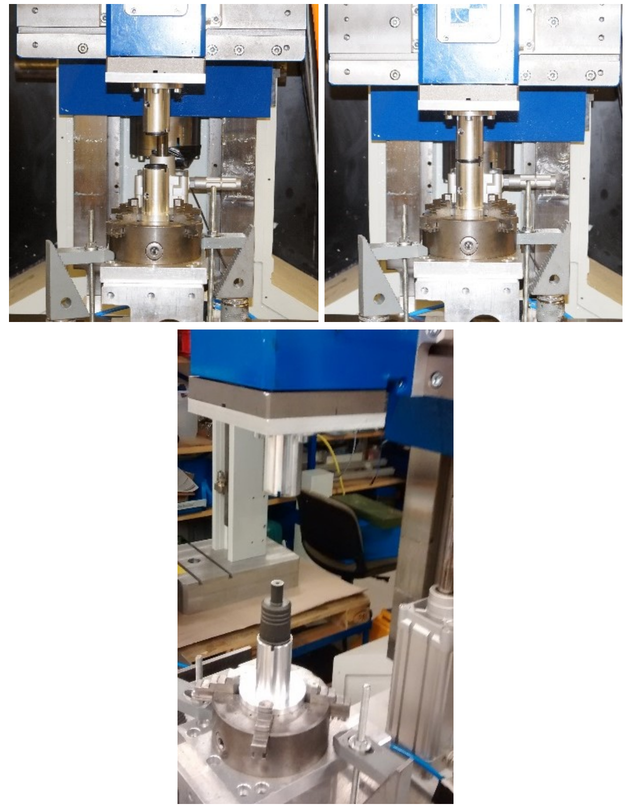

Figure 3. Welding module before, during, and after joining of PA 6.6 specimen.

Welding was conducted with five specimen per parameter set as per Table 1 with variation of welding pressure and amplitude (circular welding). Higher welding pressure usually yields lower tensile strength values [3], hence only one setup with a higher pressure value was investigated.

Table 1. Welding Parameters

Setup No.	**1**	**2**	**3**
Frequency [Hz]	130		
Seam thickness reduction [mm]	1		
Welding Pressure [MPa]	5.89	8.84	5.89
Average friction velocity [mm/s]	327	327	462

Tensile and burst pressure tests were carried out under standard climate (DIN EN ISO 139, 23°C). Test velocity for tensile testing was 1mm/s.

Burst pressure tests are conducted in a safety container with electronic pressure valve and according software to realize desired pressure ramps, see figure 4. In this case pressure for burst experiments was raised with a rate of 0.15MPa/s.

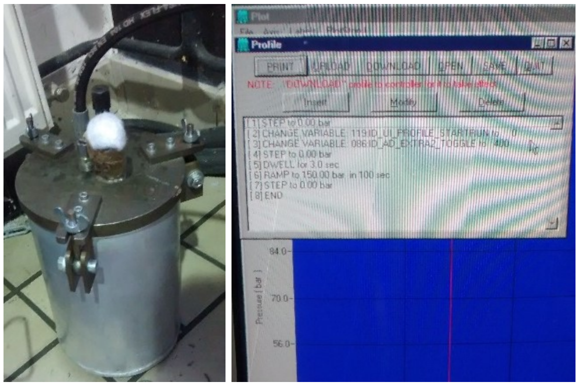

Figure 4: Safety container and plot interface for burst pressure tests.

Results and Discussion

According to the performed tests the prototype achieves with its unconventional construction weld seam quality levels comparable to those of conventional machines. Especially welding factors of PP specimen were on par with values from previous in-house radian welding tests. Lower figures of PA 6.6 specimen are likely caused by the non-optimized process parameters and disadvantageous fiber distribution and orientation in the weld seam. At this point emphasis is placed on process feasibility and reproducibility, thus no further process optimization measures were taken.

The weld factor in table 2 and 3 is calculated by dividing the measured tensile strength of the specimen through that of the base material, in this case quoting the manufacturer's datasheet.

Table 2. Tensile strength of PP specimen

Material	**PP**		
Setup No.	1	2	3
Tensile Strength [MPa]	20.13	15.97	23.06
Standard Deviation [MPa]	1.75	3.05	0.62
Weld Factor	0.56	0.44	0.64

Table 3. Tensile strength of PA 6.6 GF 30 specimen

Material	**PA 6.6 GF 30**		
Setup No.	1	2	3
Tensile Strength [MPa]	23.21	20.80	20.63
Standard Deviation [MPa]	0.89	0.52	1.06
Weld Factor	0.19	0.17	0.17

Results for tensile strengths in Table 2/3 and Figure 5 confirm the flexible joining center's capability for reproducibility of welding results with standard deviation peaking at 3.05 MPa in the least favorable setup for PP (high welding pressure). Apart from this value and taking the non-optimized process parameters into account, standard deviation remains in a narrow tolerance range and is comparable to previous in-house welding results with traditionally constructed machines.

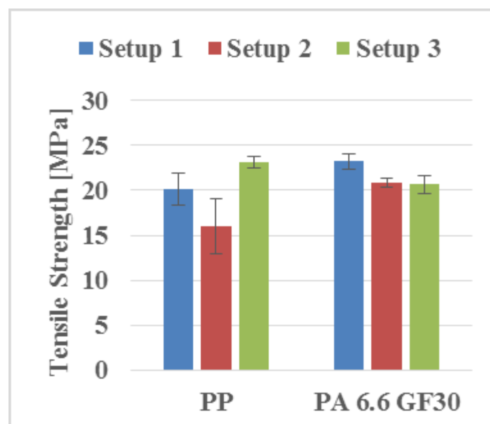

Figure 5. Tensile testing results.

Burst pressure test results point into the same direction as tensile test results, showing slightly lower overall standard deviation values based on the burst pressure average per setup and material, see figure 6.

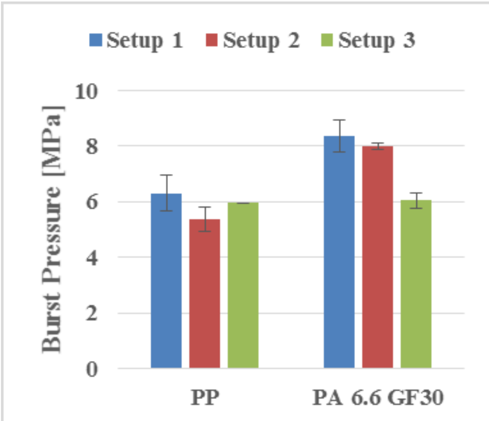

Figure 6. Burst pressure test results.

Conclusions

The main objective which was to investigate whether sufficient reproducibility values could be realized with this novel construction design as a flexible joining center has been achieved. Not only are the standard deviation values in a perfectly acceptable range, but also show absolute tensile and burst pressure values generated from specimen of non-optimized welding processes the competitive capacity of this construction compared to traditional machines. These results could be realized despite the fact that traditional machine designs typically feature higher structural stiffness through a less flexible setup which has up to now proven advantageous for process quality.

Planned project activities include process parameter optimization for all welding modules, reproducibility testing for the actuated x-, and y-axes utilizing a defined group of specimen distributed over the whole machine table, and the implementation of frequency and velocity sensors for higher process precision and on-line quality control.

For improved welding results with particular material and geometry combinations an automated pre-heating module is in preparation. A later commercial version may include an automatic module change system with a magazine, but as these are state-of-the-art in assembly cells they are not part of this project scope.

References

[1] Grewell, D. A. and Benatar, A. (2009), Comparison of orbital and linear vibration welding of thermoplastics. Polym Eng Sci, 49: 1410–1420. doi: 10.1002/pen.21254

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