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Increase of the efficiency in hot gas welding by optimization of the gas flow

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Keywords

Hot Gas Welding, Nozzle Development, Plastic Welding, Polyamide, Process Time

Abstract

The standard hot gas welding process uses a nozzle system consisting of multiple round tubes. With the top nozzle system, the weld seam is encapsulated to minimize heat loss and allow better control of the hot gas flow. This significantly reduces the required heating time of the polymer. Temperature measurements and welding tests with plates of various thicknesses and burst pressure specimens are performed to verify the improvements of the top nozzle. For polyamides with different base polymers and different glass fiber contents, an average reduction in heating time of up to 50 % is possible on average. The achieved weld strengths or burst pressures for the tested materials are comparable or higher with the top nozzle system. The top nozzle makes the process more economical due to a short cycle time and lower gas consumption. It can be added to existing hot gas tools. In addition, a larger process window, shorter heating time and higher achievable temperatures with the top nozzle lead to a higher acceptance of hot gas welding in industries. New weld able materials in turn open up new application areas and markets.

1 Introduction

For joining technical polymer components, welding processes with contact and non-contact heating have become established in series production. In recent years, non-contact joining processes such as laser, infrared or hot gas welding have been increasingly used for welding engineering polymers. More complex requirements in automotive engineering, also for electro mobility, have led to an increasing use of engineering polymers with selected properties. In the automotive industry in particular, hot gas welding is used for particle-free joining of glass-fiber reinforced polyamides (PA6 and PA66) for demanding components of larger dimensions. The welding process for a plastic component has a significant influence on the formation of particles in the component. The formation is determined by the heating principle [1, 2]. Depending on the joining process, subsequent cleaning is necessary to comply with the cleanliness limits usually required in the automotive industry. The reason for this is the formation of particles, e.g. in friction welding or the adhesion of melt to the heating surface in hot plate welding. This is increasingly listed as an exclusion criterion when selecting a suitable joining process for engineering polymers (e.g. polyamides). During friction welding, particles with a length of several millimeters are produced in the cold friction phase and remain in the component [1]. The adhesion of the fusion layer during hot plate welding can negatively influence the strength of the welded joint and occurs mainly with low-viscosity materials such as PA6 and PA66 [3]. For these materials, welding processes such as laser, infrared or hot gas welding are suitable methods.

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Hot gas welding is a further development [2] of the widely used hot plate welding [4–6]. The advantage of hot gas welding is not only the non-contact heating but also the free design of the weld seam. In contrast to the usual welding processes such as ultrasonic or vibration welding, three-dimensional weld seams can be produced comparatively easy [2, 7]. The disadvantages of the process are the high complexity of the tools, relatively long cycle times and high-energy consumption [2, 8]. The entire welding contour of both halves of the component to be joined is reproduced with small, closely spaced tubes. The hot gas flow emerging from the tubes melts the polymer at the joining surfaces. The components are then joined together under pressure (Figure 1). The conventional “round nozzle” currently used creates an impingement flow that heats the joining zone of the part. This type of nozzle produces comparatively high heat losses as well as surface temperatures that are difficult to control. The round nozzle system has long heating times because the hot gas flows off in an uncontrolled manner after hitting the polymer surface. These are the disadvantages of the round nozzle system, at which the new “top nozzle” comes in [9, 10].

Typical hot gas welded components are containers, tanks, oil guides or valve blocks for the automotive industry, but also battery housings for electro mobility. Hot gas welding is also used in medical technology.

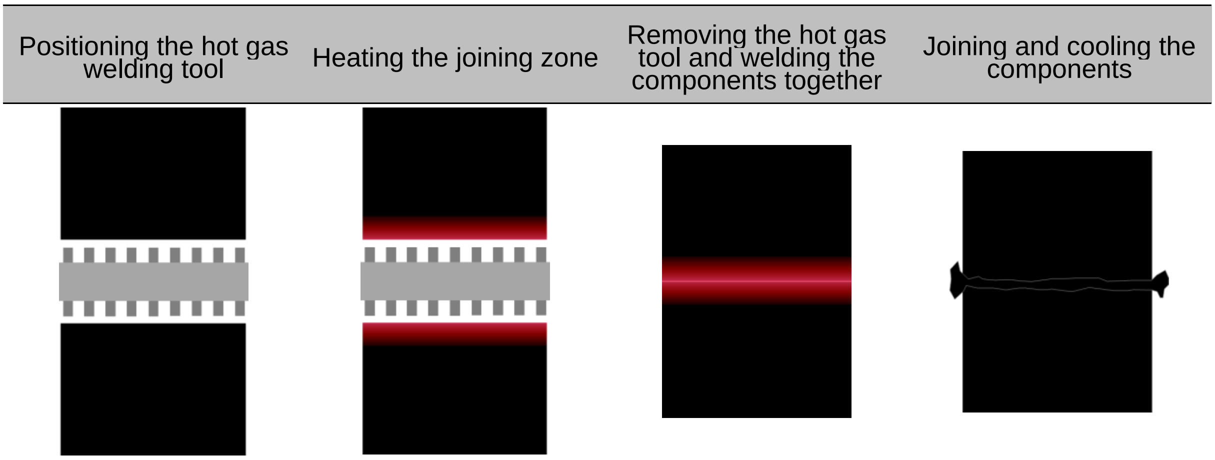


Figure 1: Hot gas welding sequences

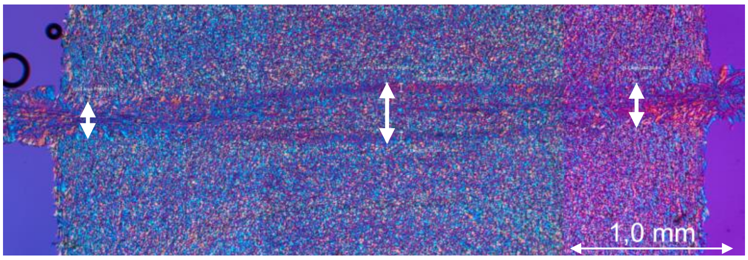
2 Research into a new nozzle concept

2.1 The melting behavior of the nozzle concepts

A nozzle system consisting of a series of round tubes (hereafter referred to as the "round nozzle") is used in the conventional hot gas welding process. The round nozzle heats the polymer by an impingement flow (Figure 2, right), which leads to crater-like structures on the polymer surface. Using this type of nozzle, leads to comparatively high heat losses and surface temperatures that are difficult to control. There are long heating times because the hot gas flows away laterally after hitting the polymer surface. The partial heating of the polymer leads to overheating in the center of the seam, while the edge areas are heated comparatively less (Figure 2, left). The differences in melting behavior caused by the nozzle concept are investigated using a PA66-GF35 (Zytel® 70G35HSLR BK416LM). The uneven melting of the polymer leads to a limited joining distance and a narrow process window. Furthermore, the welding process with the round nozzle is less reproducible and reacts sensitively to the smallest influencing factors.

A newly developed nozzle system, which encloses the weld seam during heating (hereafter referred to as the "top nozzle"), enables a significant reduction in the required heating time of the polymer. With the top nozzle, the plastic component is immersed at least 0.5 mm into the nozzle (Figure 3, right). By enclosing the weld seam, the hot process gas is prevented from flowing off to the side in an uncontrolled manner. This enables controlled flow kinematics and homogeneous melting of the weld seam. As a result, tolerance-related fluctuations in the dimensions of the polymer components can be better compensated. In addition, a larger joining distance is achieved because more polymer is melted. Due to the optimized flow profile, the top nozzle can reduce the heating time until the required melting temperatures are reached by up to 60 % for the tested materials. The heating time can be reduced from 25 s (round nozzle, Figure 2) to 10 s (top nozzle, Figure 3). At the same time, higher temperatures can be reached in a shorter time, which makes the hot gas welding process usable for technical polymers with high melting temperatures [10]. This results in a significantly shorter cycle time during welding, which leads to a reduction in the total energy consumption and thus to an optimization of the process costs [11].

$T_{hot\ gas\ tool}$	T_{gas}	process gas	t_{heat}	nozzle
475 °C	355 °C	nitrogen	25 s	round



Cut thickness: t = 10 µm;
height of recrystallization layer: 157 µm (left); 377 µm (center); 254 µm (right)

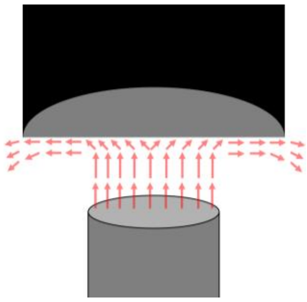
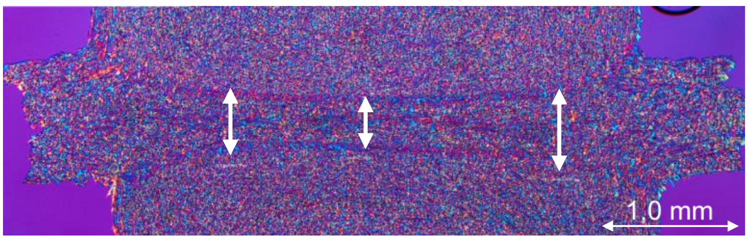


Figure 2: Thin section photo of a weld heated with a round nozzle with elliptically melted joining area (left) and melting behavior of a polymer weld, shown in section, one tube viewed; Round nozzle (distance: 2 mm) (right)

$T_{hot\ gas\ tool}$	T_{gas}	process gas	t_{heat}	nozzle
475 °C	355 °C	nitrogen	10 s	top



Cut thickness: t = 10 µm;
height of recrystallization layer: 448 µm (left); 428 µm (center); 480 µm (right)

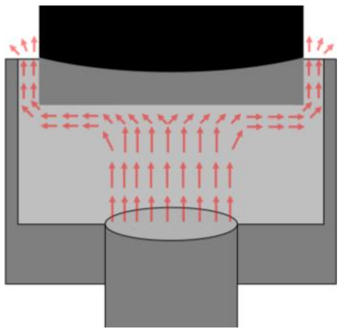


Figure 3: Thin-section photo of a weld heated with a top nozzle with a melted joining area comparable to hot plate welding (left) and melting behavior of a polymer weld, shown in section, one tube viewed; Top nozzle (distance: - 0.5 mm) (right)

2.2 Experimental setup and comparison of the heating behavior of the round and top nozzle

Temperature measurements with lost thermocouples are carried out in the welding process with the two nozzle systems to examine the heating behavior of the polymer. The investigations are performed on a hot gas welding machine of the type VDP 2012 from the manufacturer KVT Bielefeld GmbH, which is equipped with pressure sensors. The heating behavior of the polymer is measured with type J lost thermocouples. Holes (Ø 0.5 mm) are drilled at the appropriate points using a suitable CNC milling machine. Eight measuring points are provided per plate (Figure 4, right). To determine the temperature of the polymer surface, a thermocouple is inserted into the polymer surface (0.0 mm (P)). Another thermocouple is positioned at a distance of 0.1 mm from the polymer surface to measure the gas temperature on the polymer surface (+0.1 mm (G)). The other six thermocouples are positioned 0.5 mm beneath the polymer surface (-0.5 mm (P)).

Generally, the hot gas welding process can be divided into four sections: Heating the polymer, moving out the hot gas tool, joining the components and cooling the components. The polymer must be melted according to the desired welding depth. In practice, a welding depth of 0.8–1.0 mm has proven successful. The comparison of the two nozzle concepts on a PA66-GF35 shows that the heating process with the top nozzle can be shortened by up to 50 % with equivalent weld strengths.

The evaluation of the temperature measurements on a 2 mm wide weld seam shows that the top nozzle heats the polymer more efficiently (Figure 4, left). The top nozzle heats the polymer at a depth of 0.5 mm to 223 °C within 7.5 s, while the round nozzle reaches 158 °C in the same time. If you increase the heating time by another 7.5 s, the round nozzle reaches a temperature of 191 °C in the polymer. To reach comparable temperatures, the top nozzle needs a 50 % shorter heating time. With a 4 mm thick weld seam, the weld seam strength of a PA66-GF35 can be increased and the heating time of the polymer can be reduced from 22.5 s to 10.0 s.

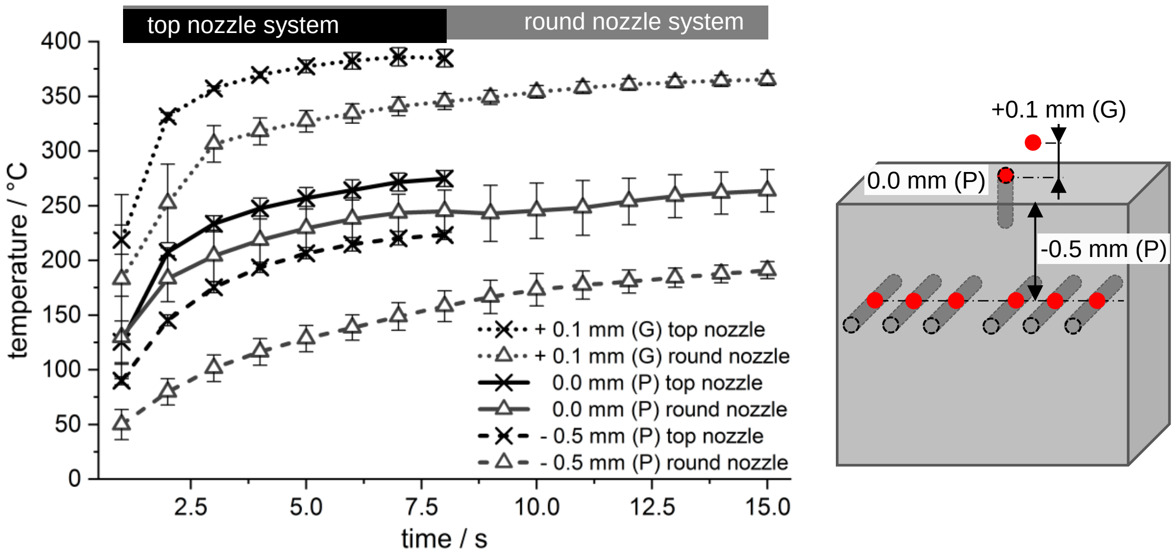


Figure 4: Comparison of the measured temperatures (lost thermocouples) with the round and top nozzle with nitrogen as process gas, weld depth of 0.8 mm and 1 MPa welding pressure on a 2 mm thick plate out of PA66-GF35; Measuring points in the left half of the polymer plate (dark grey: polymer plate, red; measuring points)

3 Welding tests on plates and pressure vessel test specimens

3.1 Test set-up for the investigation of the weld seam strength and the bursting behavior

Welding tests are carried out on plates (seam width: 2 mm and 4 mm) and pressure vessel test specimens (PVTS) in order to investigate the two nozzle systems (round and top nozzle). The resulting surface temperatures are evaluated with the IR camera system. Temperature measurements are taken with thermocouples and the built-in IR camera to validate the IR camera system. After removing the hot gas tool, the IR measurement is carried out. The measured temperatures correspond between thermocouples and the IR camera system. The temperatures of the IR camera system will be used in the further course. The comparison of the two nozzle systems is carried out on two polyamides:

- PA6-GF40 (Zytel® 73G40HSLA BK416LM – DuPont),
- PA66-GF35 (Zytel® 70G35HSLR BK416LM – DuPont).

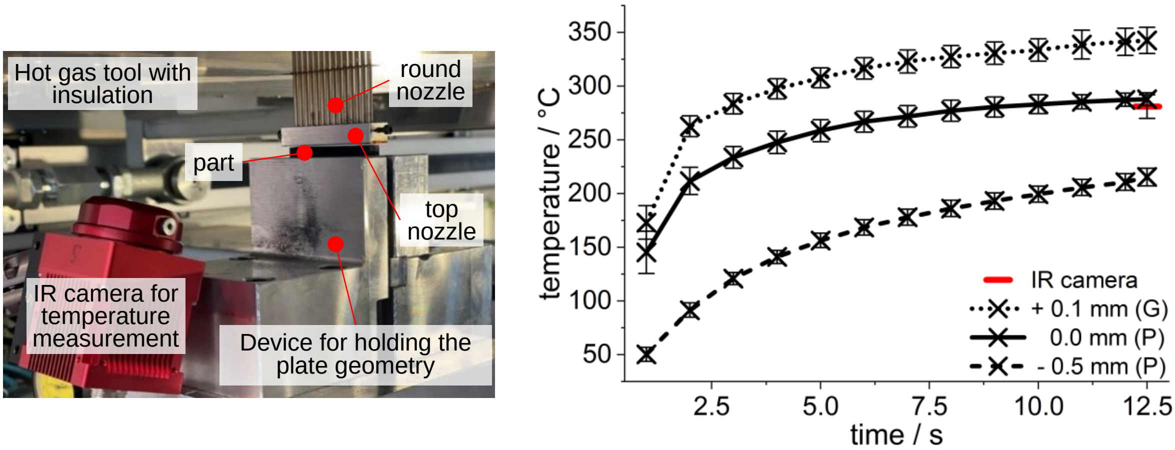


Figure 5: Measuring set-up for welding plate test specimens (left) and comparison of temperature measurements with IR camera and thermocouples an a PA66-GF35 at a heating time of 12.5 s and a gas temperature of 355 °C (right)

3.2 Influence of the heating time

The tests on a PA66-GF35 show that the surface temperature of the polymer increases with increasing heating time (Figure 6). The same behavior can be observed with PA6-GF40. Furthermore, it can be seen that the surface temperature increases significantly more with the top nozzle, in comparison to the round nozzle, at the same temperature of the hot gas tool. The higher increase is accompanied by an extension of the heating time by 5 s:

- PA6-GF40, top nozzle, 6 K/s vs. round nozzle - 1 K/s (400 °C),
- PA66-GF35, top nozzle, 7 K/s vs. round nozzle - 2 K/s (475 °C).

The tests show that the top nozzle system heats the polymer more efficiently (Figure 6, left). In addition, higher polymer surface temperatures are achieved in a shorter heating time. The standard deviations in the tests with the round nozzle system are significantly larger compared to the top nozzle system, which indicates a more unstable process (Figure 6, left). Investigations with different temperatures of the hot gas tool show that the temperature of the polymer surface increases with longer heating times. This behavior can be observed for pressure vessel test specimens (PVTS), as well as for plates with a width of 2 mm and 4 mm (Figure 6, right).

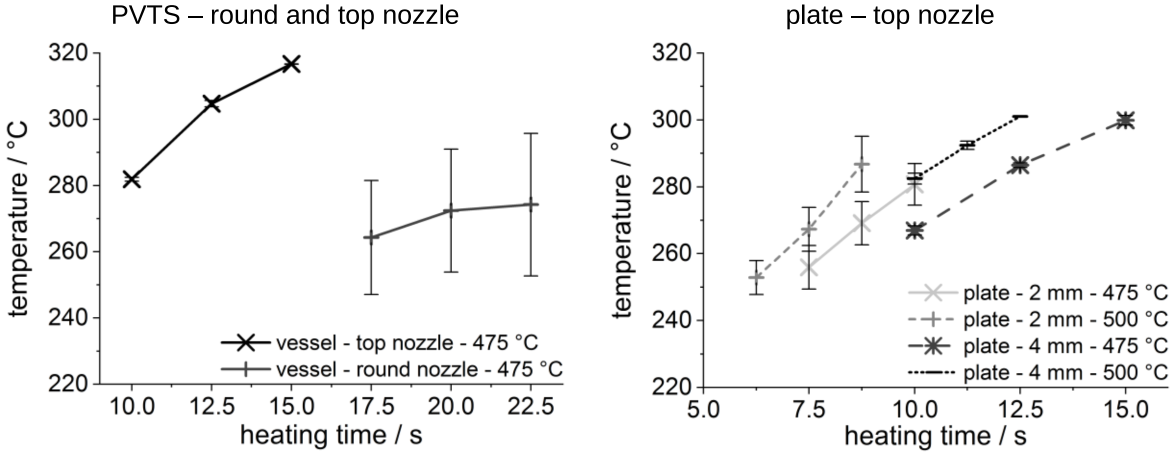


Figure 6: Influence of the heating time on the surface temperature of the polymer (PA66-GF35) on a PVTS (vessel) using the round and top nozzle (left) and plates in 2 mm and 4 mm thickness using the top nozzle (right)

3.3 Relationship between polymer surface temperature and joining pressure

When using the top nozzle system the joining pressure decreases for a PA6-GF40 and a PA66-GF35 as the surface temperature of the polymer increases after the desired weld depth has been reached. This can be explained by a greater melting depth in the polymer, which in turn leads to a lower joining pressure required for a constant welding depth. This behavior is not observable with the round nozzle system (Figure 7, left). The standard deviations in the tests with the round nozzle system are significantly larger than with the top nozzle, which makes the process more difficult to control (Figure 7, left). When welding plates with a width of 2 mm and 4 mm, this characteristic can be observed with the top nozzle at different temperatures of the hot gas tool (Figure 7, right).

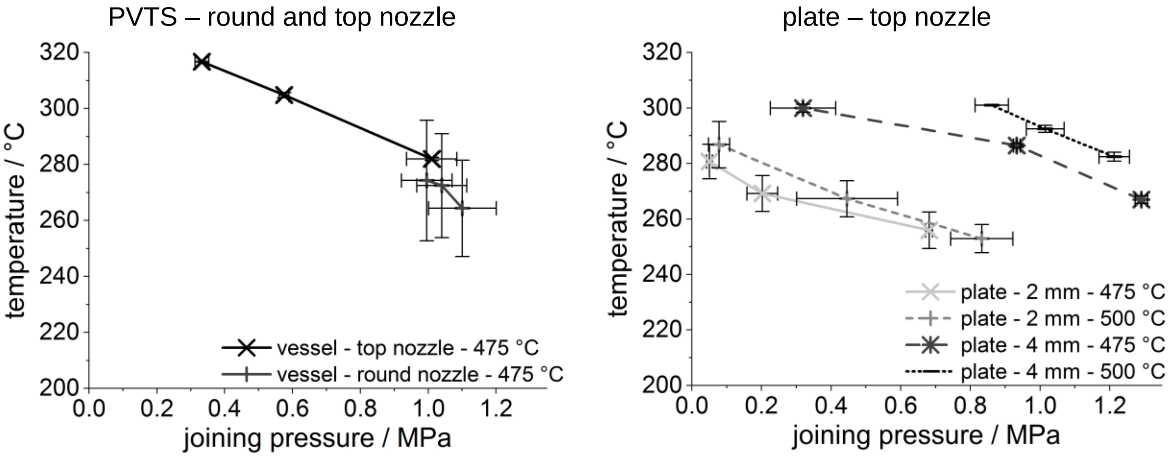


Figure 7: Influence of the temperature of the polymer (PA66-GF35) on the joining pressure on a PVTS (vessel) using the round and top nozzle (left) and plates in 2 mm and 4 mm thickness using the top nozzle (right)

3.4 Influence of the polymer surface temperature on the achievable bursting pressure

The investigations on a PA6-GF40 and a PA66-GF35 with the top nozzle show that increasing surface temperatures lead to higher burst pressures. A surface temperature of the PA6-GF40 of 275 °C leads to a burst pressure of more than 18 bar. For the round nozzle, a surface temperature of 250 °C leads to a burst pressure of 16 bar (PA6-GF40). The standard deviations are significantly larger compared to the top nozzle, and thus the reproducibility is lower. At a surface temperature of the polymer of 317 °C, burst pressures of 15 bar can be achieved when testing PA66-GF35 with the top nozzle (Figure 8, left). With the round nozzle system, burst pressures of only 13 bar are achieved with larger standard deviations (Figure 8, left). When using the top nozzle, an increasing surface temperature of the polymer leads to a higher weld strength or higher burst pressures. This can be demonstrated at different hot gas tool temperatures on pressure vessel test specimens (PVTS) and plates with a thickness of 2 mm and 4 mm (Figure 8, right).

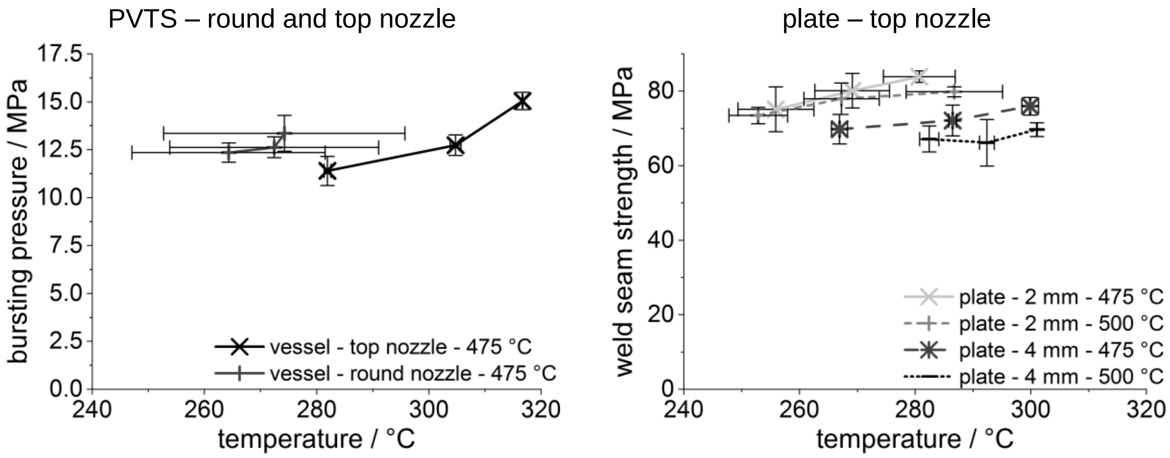


Figure 8: Relationship between surface temperature of the polymer (PA66-GF35) and bursting pressure on a PVTS (vessel) using the round and top nozzle (left) and plates in 2 mm and 4 mm thickness using the top nozzle (right)

3.5 Influence of the joining pressure on the achievable bursting pressure

The tested PA6-GF40 and PA66-GF35 show that the achievable burst pressures increase with decreasing joining pressure with the top nozzle system. The highest burst pressures (18 bar) can be achieved with joining pressures of less than 0.5 MPa with a PA6-FG40. In case of the PA66-GF35 a joining pressure of less than 0.5 MPa leads to the highest burst pressures (15 bar) when using a top nozzle (Figure 9, left). This characteristic cannot be observed clearly with the round-nozzle system (Figure 9, left). When using the top nozzle, decreasing joining pressure leads to increasing weld strengths or higher burst pressures. On pressure vessel test specimens (PVTS) and plates with a thickness of 2 mm and 4 mm, this can be demonstrated at different hot gas tool temperatures (Figure 9, right).

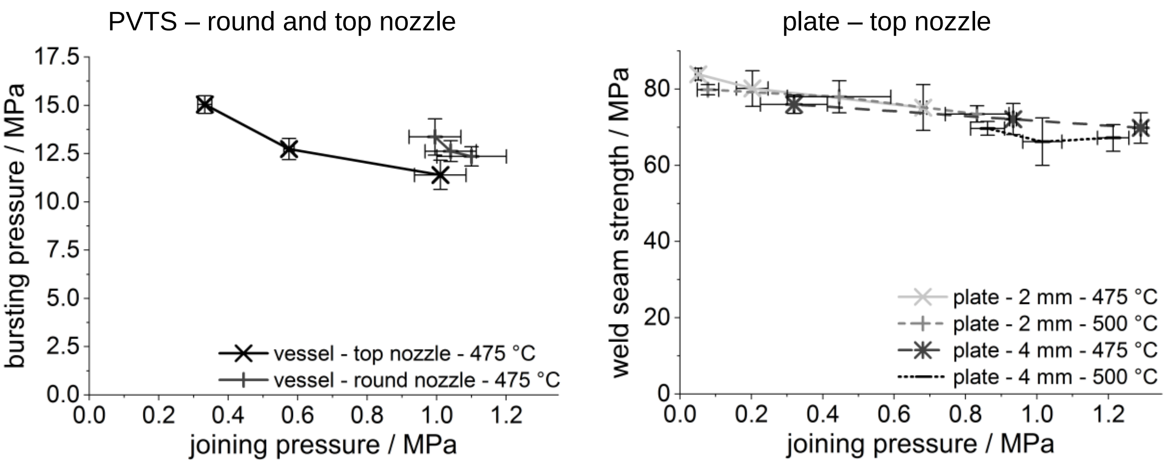


Figure 9: Relationship between joining and bursting pressure on a PVTS (vessel) using the round and top nozzle (left) and plates in 2 mm and 4 mm thickness using the top nozzle (right) using a PA66-GF35

4 Discussion and conclusion

The top nozzle encloses the weld seam, which minimizes heat loss and allows better control of the hot gas flow. The more efficient heating of the polymer is confirmed by temperature measurements and welding tests with plates of various thicknesses and pressure vessel test specimens (PVTS). For polyamides with different base polymers and different glass fiber contents, a reduction in average heating time of up to 50 % is possible while the weld strength achieved is comparable or higher. The investigation on PA6-GF40 shows, that surface temperatures between 235 °C and 280 °C for plates and surface temperatures between 275 °C and 290 °C for pressure vessel test specimens lead to the highest weld strengths or burst pressures. For PA66-GF35, surface temperatures of 285 °C to 290 °C lead to the highest weld strengths (plate) and 300 °C to 320 °C to the highest burst pressures (PVTS). A lower joining pressure leads to the highest burst pressures for the investigated materials. For PA6-GF40, joining pressures of below 0.8 MPa (plate) and 0.4 MPa (PVTS), and for PA66-GF35 of below 1.0 MPa (plate) and 0.6 MPa (PVTS), lead to the highest weld strength/burst pressures. A set of useful process parameters while using the top nozzle system is shown in Table 1.

The top nozzle improves the economy of the process through a short cycle time and lower gas consumption. It can be added to existing hot gas tools. In addition, a larger process window, shorter heating time and higher attainable temperatures lead to a higher acceptance of hot gas welding when using the top nozzle. Due to the high melting temperature the joining of reinforced polyphthalamide types (PPA) using hot gas welding was previously difficult to implement. With the top nozzle system, it will now be possible to join different polyphthalamides and achieve comparatively high weld strengths.

PPAs have excellent chemical resistance and good mechanical properties, even at higher temperatures. Furthermore, their low moisture absorption compared to PA6 and PA66 types allow the use with increasing requirements on the dimensional stability. One area in which semi-aromatic polyamides are becoming more and more relevant on the market are thermal management modules, which enable precise temperature control of numerous systems in the automobile. Further examples of commercial applications can be found in the field of pumps, water-carrying components, thermostat housings and in future-relevant applications in electric and fuel cell vehicles. New weld able materials, in turn, open up new fields of applications and markets.

Table 1: Useful process parameters for welding with top nozzle

	PA6-GF40 Zytel® 73G40HSLA BK416LM	**PA66-GF35 Zytel® 70G35HSLR BK416LM**
melting temperature	220 °C	263 °C
joining temperature	plate: 235–280 °C	plate: 285–290 °C
	vessel: 275–289 °C	vessel: 305–320 °C
joining pressure	plate: 0.05–0.80 MPa	plate: 0.3–1.0 MPa
	PVTS: 0.26–0.40 MPa	PVTS: 0.33–0.58 MPa
achievable weld strength	69–74 MPa	70–76 MPa
achievable burst pressures	16,8–18,5 bar	12,7–15,0 bar

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