# CYCLE TIME REDUCTION BY FORCED AIR COOLING FOR HOT PLATE WELDING

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ABSTRACT

Hot plate welding is one of the most popular methods for joining plastics by utilizing heat conduction to plasticize and join thermoplastics. In comparison to competitive welding processes, hot plate welding generates high weld seam qualities but is characterized by a long cycle time; from 20 s, for small parts, to about 30 min. Cycle time itself is dominated by the cooling time. This paper reports on the influence of different cooling methods to reduce the cooling time for hot plate welding of polymers. In the initial investigations, water and nitrogen were used as cooling media (free convection) and were compared with compressed air (forced convection). The results of the initial investigations lead to more detailed analyses of forced cooling by compressed air. In the subsequent investigations, different parameters of compressed air were examined to reduce cooling time while retaining the weld seam quality. The parameters of compressed air: air flow, temperature and humidity were analysed to optimize the cooling time for amorphous and semi-crystalline polymers. It was found that the reduction of cooling time by compressed air leads to good results. Cooling time savings of 85 % could be achieved. Additionally, the weld seam quality was investigated by measuring the weld seam strength and analysing residual stresses. The weld seam strength is not influenced by the cooling method, but the cooling method influences the size of the stress field of the welded specimens.

***IIW-Thesaurus keywords:*** Cooling; Plastics; Thermoplastics; Time.



## 1 Introduction

Hot plate welding is a widely used and reliable technique for welding thermoplastics in batch and mass production [1]. It is used in different areas, for instance in various production applications; welding of pipes and joining of films. Typical product applications are fuel tanks, headlamps, automotive batteries or plastic barrels. In comparison to competitive processes like ultrasonic and vibration welding, hot plate welding is distinguished by a long cycle time, from 20 s, for small parts, to 30 min. In order to increase productivity, the reduction of the cycle time is of great interest for commercial manufacturers.

The process of hot plate welding consists of matching and heating the parts to generate a molten layer of a specific thickness, removal of the hot plate and joining and cooling to fuse the molten surfaces [2]. The analysis of the cycle time leads to the conclusion that the cooling time has the largest influence on the cycle time. In order to raise productivity, the approach adopted in this work deals with the reduction of the cycle time by using different cooling methods without affecting the weld quality. The results will lead to a more detailed analysis of cooling methods.

By applying different cooling methods, the cycle time can be shortened, thereby production costs could be brought down and efficiency could be increased [3]. The choice of the cooling method (compressed air, water and nitrogen) also depends on efficiency and technical feasibility. This paper focuses on the question; which cooling method and which parameter of compressed air ultimately exert the most influence on the cooling time or the weld quality?

## 2 Objectives

Currently, the DVS (German Welding Society) [4] only refers to empirical applications for the determination of the cooling time for hot plate welding. These guidelines are limited to general advice and stipulate several parameters that should be taken into consideration, such as the ambient temperature or the size of the joining surface. For batch production, a cooling time between 10 and 30 s is common for 2 mm-thick specimens. In order to shorten the cooling time and raise the productivity, the basis for shortening and optimizing the cooling rate was examined. Also, environmental and process conditions were taken into account.

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## 3 Test set-up

For the purposes of the research project, standard test specimens (DIN EN ISO 527), whose shape is a semi-tensile bar having a thickness of 2 mm, were produced from amorphous (PC, Makrolon AL 2647) and semi-crystalline (PP, Moplen HP 501 L) materials. These test specimens were welded, subjected to displacement control, to their optimum tensile strengths (Table 1) at a temperature of 275 °C and 238 °C for amorphous and semi-crystalline materials, respectively. In all the experiments, the hot plate was wrapped with Teflon® cloth to minimize the melt sticking to the hot plate. The ratio between the molten layer thickness and the joining displacement was a constant of 0,75. The shift time was fixed at 2 s. The molten layer thickness for both mating parts was set to $L_0 = 2{,}2$ mm and $L_0 = 0{,}7$ mm for the amorphous and the semi-crystalline materials, respectively (to compute the molten layer thickness, the squeezed out flash and the carriage displacement was measured).

In the preliminary investigations, different cooling methods, involving different cooling media, were tested in order to examine the influence of forced cooling on the quality of the weld. The selected cooling media were intended to bring about an increase in the cooling rate. The selected media were:

- water (17 °C),
- liquid nitrogen (–150 °C),
- compressed air (4 m³/h).



The water and nitrogen cooling media were employed outside of the clamps. Following the joining phase, the specimens had to be removed manually from the clamps and placed in the cooling medium, which took between 5 and 7 s. The compressed air could be used directly on the hot plate welding machine. Air channels were made in the existing clamping jaws (Figure 1). This meant that the compressed air could be applied selectively to the weld, immediately after the specimen parts had fused. In this study, the specimens were cooled from both sides. On each side, two nozzles were situated at an angle of 45°. The parts were subsequently destructively tested using a weld tear strength machine. In comparison to the base material's strength determined previously, the results provide information on the weld quality which is influenced by the cooling conditions.

In subsequent investigations, the tensile strength, as a typical index of weld quality, has to be controlled in order to examine the influence of different compressed air parameters on increasing the cooling rate. The selected parameters for the compressed air are:

- humidity (13-50 %),]
- air flow (2-5m³/h),
- temperature (10-28 °C).

The different test set-ups were realized by using a compressed air regulator to adjust the volume flow rate, a cyclone tube to vary the temperature and a compressed air lubricator (filled with water) was used to increase the humidity of the compressed air. After the compressed air was adjusted according to the test requirements, it must be fed to the weld seam at the right moment. For this purpose, the experimental set-up used a mechanically actuated valve in combination with a time actuated valve to feed the air to the weld seam at the right moment. The moving of the clamping device activated the mechanically actuated valve which released the airflow which in turn, activated the time actuated valve. The delay time of the time actuated valve was set to 0,8 s, so the air reached the

**Table 1 – Parameters**

| Structure | Material | Hot plate temperature [°C] | Melt layer thickness [mm] | Pressureless heating [s] |
|---|---|---|---|---|
| Amorphous | Makrolon AL 2647 (PC) | 275 | 2,2 | 22,5 |
| Semi-crystalline | Moplen HP 501 L (PP) | 238 | 0,7 | 7,5 |

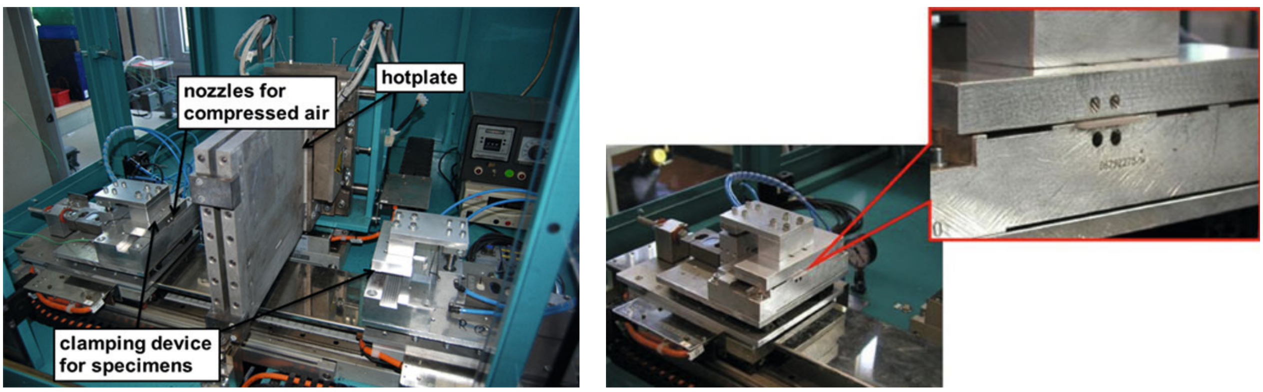


**Figure 1 – Welding set-up**

specimen after the joining displacement was realized. The compressed air parameters used are shown in Table 2.

To investigate the influence of the air flow, settings of 2 $m^3/h$ (V1), 4 $m^3/h$ (V2) and 5,5 $m^3/h$ (V3) were employed at a constant temperature (28 °C) and a relative humidity (40 %). The temperature influence was investigated at 10 °C (T1), 17 °C (T2) and 21 °C (T3) at a constant air flow (5 $m^3/h$) and absolute humidity (3 g/kg). The relative humidity depends on the temperature while the absolute humidity remains constant. Further information about the interaction of the compressed air parameters can be taken from a Mollier-diagram [5]. The relative humidity varies between 30 % (X1) at 24 °C, 40 % (X2) at 23 °C and 50 % (X3) at 23 °C with a constant air flow of 5 $m^3/h$.

As a basis for the experiments, the free convection with air (24 °C) was investigated. The determined values for the tensile strength and cooling time are used to evaluate the forced convection at the described conditions. The temperature development during the welding process was measured with thermocouples (J Type) at a distance of 1 mm (Figure 2) from the weld seam before the squeeze flow. For these experiments, 3 samples were welded and tested for the temperature measurements.

All the welded specimens were tested at room temperature in tension using standardized tensile testing equipment (Zwick&Roell – Model 1446). The crosshead speed was set to 50 mm/min. The weld strength was calculated by using the maximum breaking load.

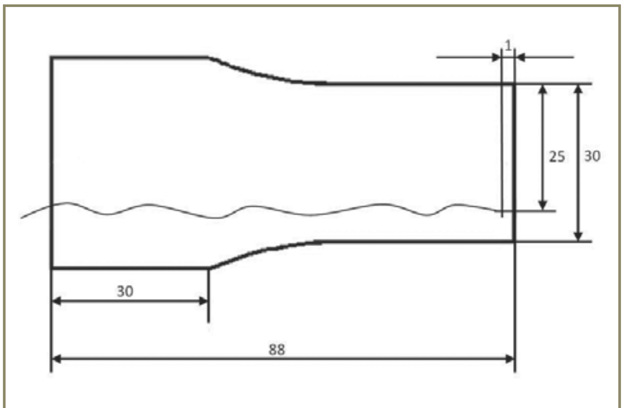

Figure 2 – Positioning of thermocouple in the test specimena

## 4 Results

Two different objectives were set: On the one hand, the objective was to retain the specimens' weld strength and, on the other hand, to reduce the cooling time.

In the preliminary investigations, the influence of different cooling methods was investigated. A comparison of the different cooling methods clearly shows that the type of cooling has no notable influence on the weld strength, cf. Figure 3 for PC and PP.

By specifying a removal temperature of 60 °C, it is possible to record the cooling time for different cooling methods from the start of cooling to the point where the removal temperature is attained. The cooling times of water and nitrogen do not include the handling time of 5-7 s. The reduction in cooling time is shown in Figure 4. Taking the handling time into account, cooling with compressed air has the shortest cooling time (PC: 8,43 s and PP: 10,5 s).



Table 2 – Compressed air parameters

| | | Volume flow [$m^3/h$] | Temperature [°C] | Relative humidity [%] | Absolute humidity [g/kg] |
|---|---|---|---|---|---|
| Free convection | | | | | |
| | | – | 31 | 40 | 9,45 |
| Forced convection | | | | | |
| Volume flow variation | V1 | 2 | 28 | 13 | 3 |
| | V2 | 4 | 28 | 13 | 3 |
| | V3 | 5,5 | 28 | 13 | 3 |
| Temperature variation | T1 | 5 | 10 | 40 | 3 |
| | T2 | 5 | 17 | 25 | 3 |
| | T3 | 5 | 21 | 20 | 3 |
| Humidity variation | X1 | 5 | 24 | 30 | 5,5 |
| | X2 | 5 | 23 | 40 | 7 |
| | X3 | 5 | 23 | 50 | 8,7 |

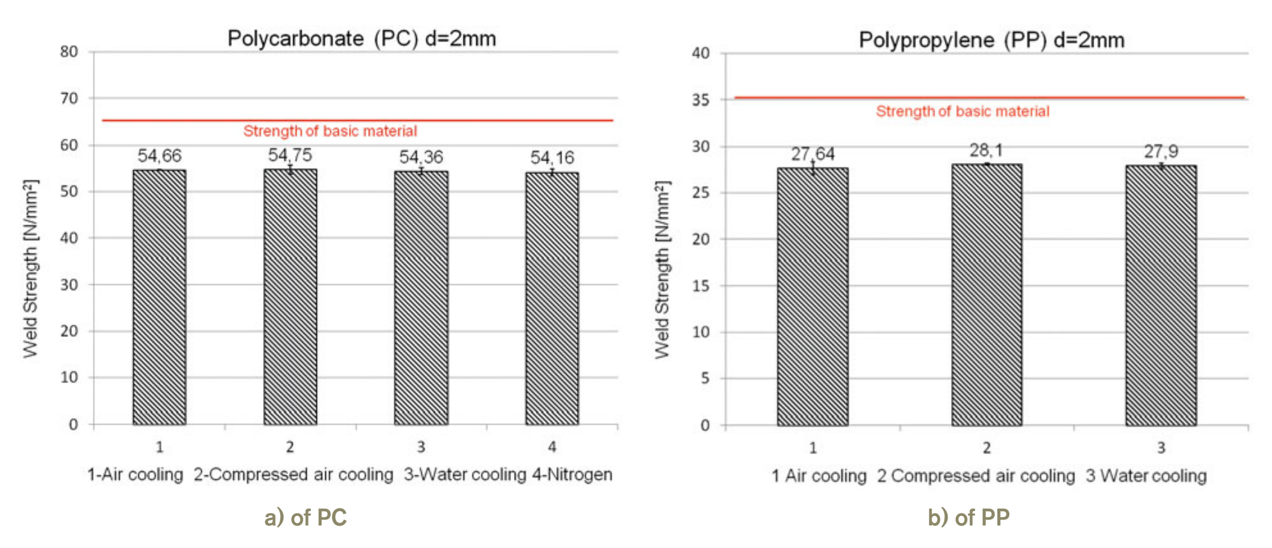


**Figure 3 – Weld strength as a function of the different cooling methods**

In addition to the study of the cooling time reduction, the influence of cooling media on the residual stresses and the structure of the materials were investigated. By using photoelastic stress analyses and measuring the geometry of the lenticular field, it was possible to qualitatively grade the influence of the different cooling media on the stresses in the welded parts. In experiments for this paper, the length (a+b) of the residual stress-influenced field was measured orthogonally on both sides of the joint's interface. These results were collated as an average value (Figure 5).



The measured stress fields produced by the different cooling methods are compared to the results expressed in terms of standard air cooling and shown in Figure 6.

An evaluation of Figure 6 would suggest that cooling the specimen with compressed air reduces the size of the inherent stress field in comparison to standard cooling.

Owing to the preliminary results, the subsequent investigations analysed the potential of the compressed air parameters in more detail. In Figure 7a), the basic material strength of PC is located at 71 N/mm² and is comparable to the strength of a welded specimen cooled by free convection. The strength of 69 N/mm² demonstrates a small decrease for the welded specimens with various air flows, temperatures and humidities. In Figure 7b), the strength of the basic material PP is shown. The basic material strength of 35,4 N/mm² is not attained by the welded specimens either by free convection or by forced cooling. A comparison of the different test parameters clearly shows no notable influence on the weld strength. Compared to the preliminary investigations, it is obvious that the strength of the polycarbonate has increased. In the intervening time between these two studies, the specimens were stored for more than one year, so that physical ageing processes (e.g. plasticizer loss) may have resulted in an increase in the material's strength [6].

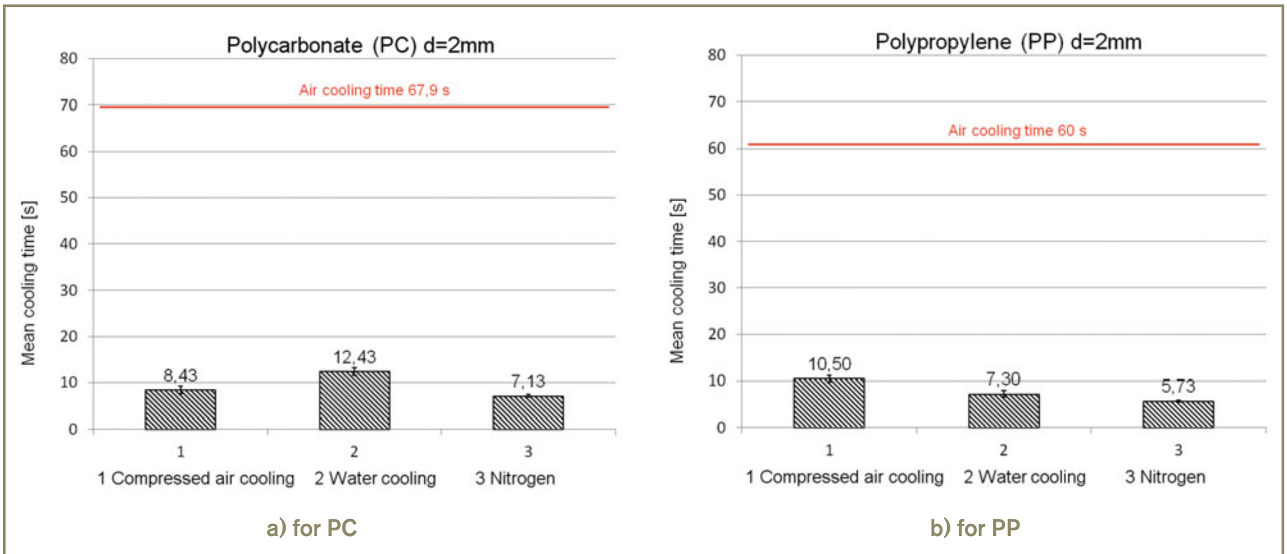


**Figure 4 – Mean cooling time as a function of the different cooling methods**

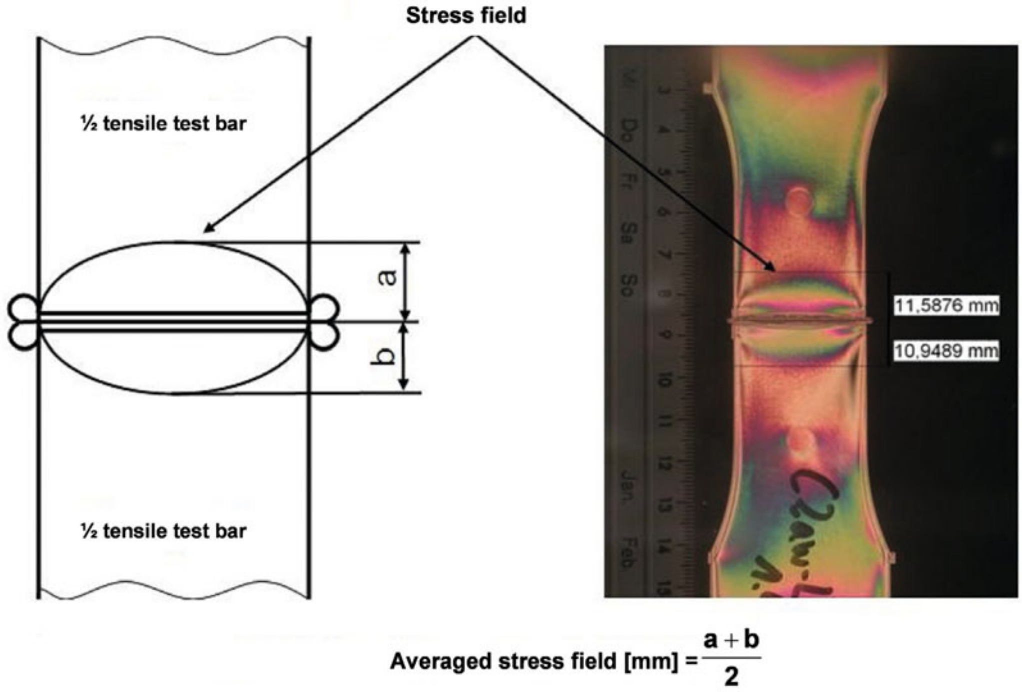


Figure 5 – Photoelastic stress fields produced by the influence of the different cooling methods

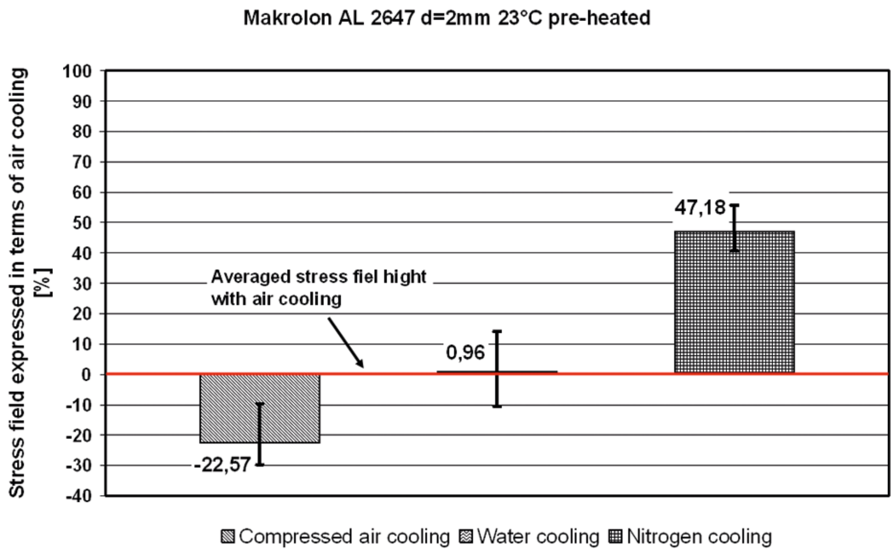


Figure 6 – Size of the photoelastic stress field for different types of cooling for a polycarbonate (PC), expressed as a percentage in terms of cooling in air



In order to determine the cooling rate for different compressed air parameters, it was necessary to measure the temperature inside the welded part during cooling. In this way, the cooling time which is needed to classify the different cooling methods can be determined. Figure 8 shows the reduction of cooling time in relation to the free convection by using compressed air for both materials. This evaluation illustrates that the volume flow has the largest influence on the cooling time, while humidity and temperature effects are comparably small and indistinct.

In Figure 9, the temperature development is shown during the welding process. The different phases of hot plate welding can be discerned; such as the temperature increase during heating, shifting, joining and finally cooling. Thermal conduction, caused by melt squeezing during the joining, leads to an increase in temperature after the shift.

It is possible to reduce the cooling time for PC by up to 53,8 s by using a volume flow of 20 $m^3/h$ (V3), a start temperature of about 230 °C, a removal temperature of 60 °C and a compressed air temperature of 28 °C. 21,1 s can be saved when the removal temperature is set to 100 °C, and with a removal temperature set to the softening temperature of PC (135 °C), 6 s can be saved.

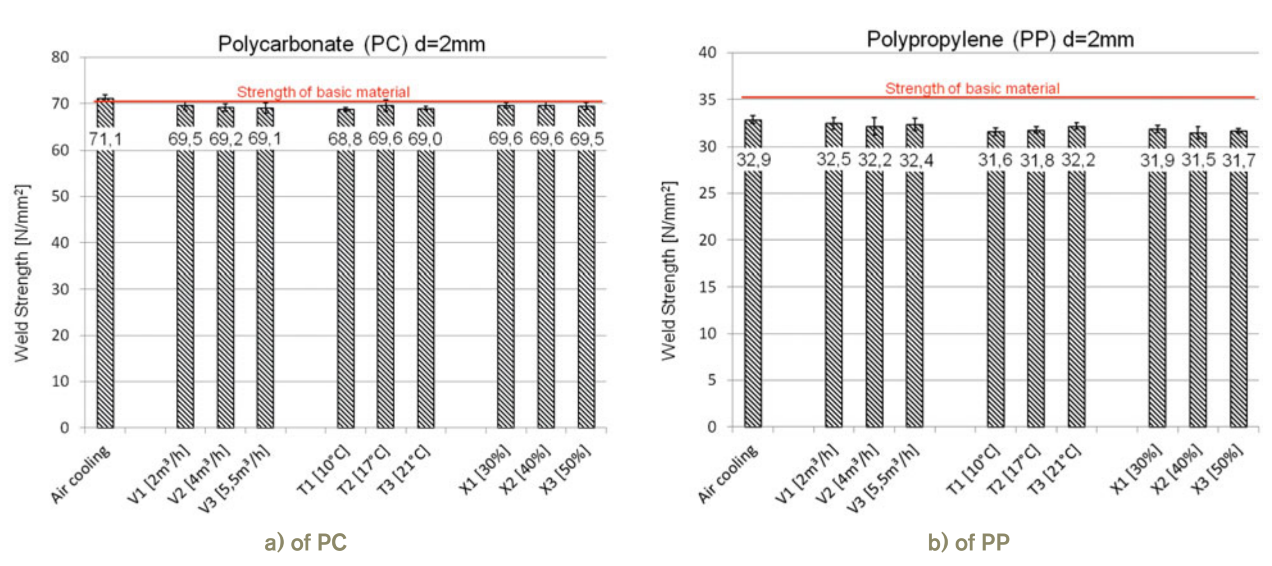


**Figure 7 – Strength as a function of different compressed air parameters**

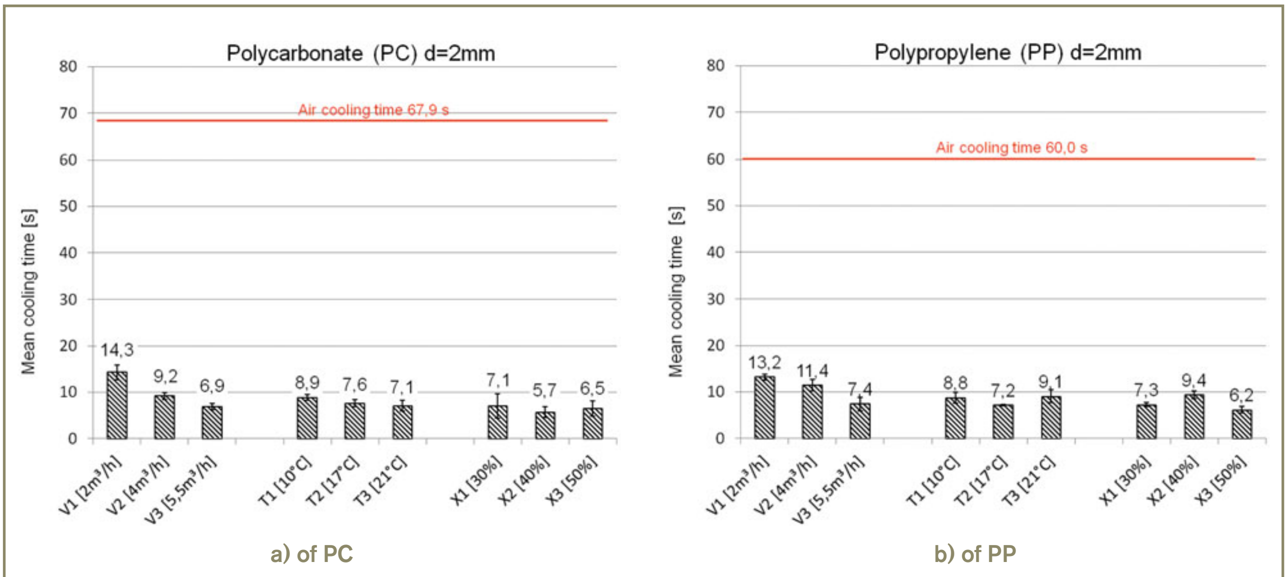


**Figure 8 – Mean cooling time as a function of different air parameters**

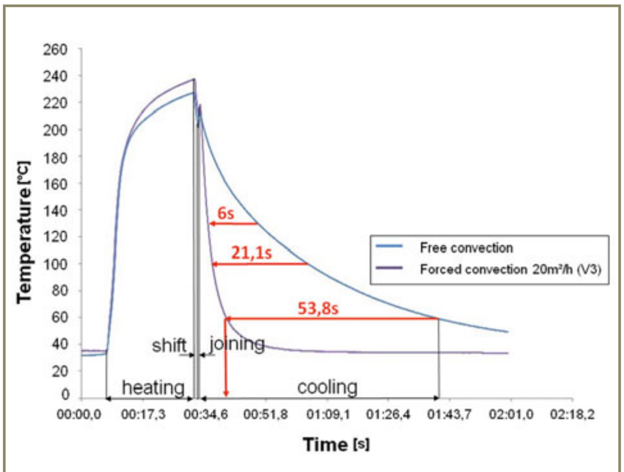


**Figure 9 – Free convection vs. forced convection (20 m³/h) for PC**

The welding machine is a prototype (Bielomatik – K2150) which has linear actuators and load cells on each clamping device. This prototype allows one to set and to measure the following parameters during the welding process: time, position, speed, acceleration, and force. The maximum tensile strength that was recorded corresponds to the maximum tearing force of approximately 900 N for the welding machine employed. Here, the test series (crosshead speed 50 mm/min) was restricted to the cooling medium of compressed air (5 $m^3$/h) since the cooling medium was fed directly to the hot plate welding machine without having to remove the specimen. Figure 10, shows the tear strength's curve subjected to standard cooling in air and compressed air cooling measured directly on the welding machine (3 samples per parameter set).

The mean saved cooling time is evaluated using the boundary conditions of a short-term strength that remains

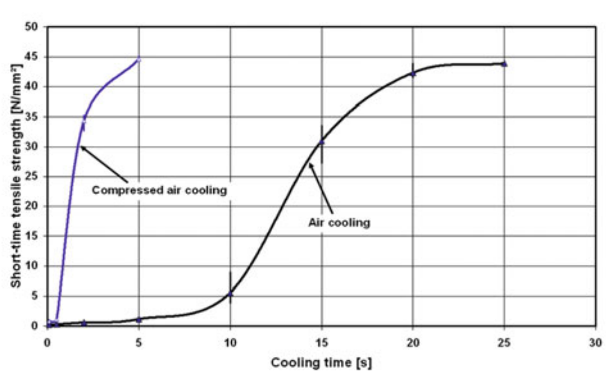


Figure 10 – Weld strength against cooling time subjected to air and compressed air cooling for a PC (Makrolon AL 2647 d = 2 mm; 23 °C)

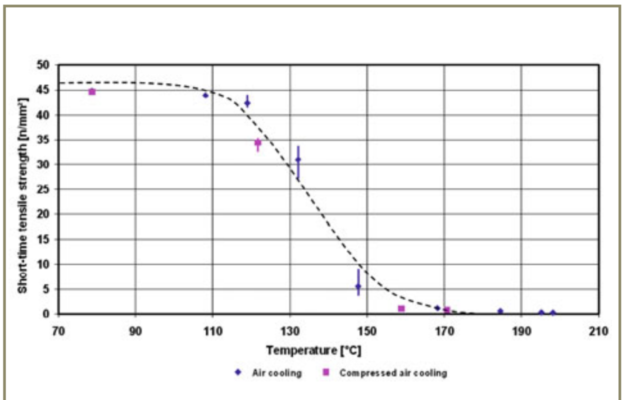


Figure 11 – Weld strength against the internal temperature of the part subjected to air and compressed air cooling for a PC (Makrolon AL 2647 d = 2 mm; 23 °C)

the same (30 N/mm²). A reduction of some 13 s can be achieved by employing compressed air cooling. Figure 11 shows the weld strength plotted against the part's internal temperature (3 samples per parameter set). The weld strength is directly linked to the temperature of the melt. The weld strength to remove the specimen is reached at a temperature lower than 100 °C for PC.

## 5 Conclusion

The tests conducted emphasize the influence of the volume flow rate on the cooling time without reducing the weld quality. By using compressed air it is possible to shorten the cooling and the cycle time. Cooling time savings of 85 % could be achieved. The reduction of cooling time can increase the productivity and competitiveness compared to other welding processes. The method of forced cooling by means of compressed air can contribute to a greater dissemination of hot plate welding. Further investigations will deal with other parameters of compressed air cooling and will include mathematical approaches.

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