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ANALYSIS OF CHANGES IN THE PROPERTIES OF POLYMERIC COMPONENTS JOINED BY RESISTANCE WELDING

The article has been devoted to issues connected with socket fusion welding, which is next to welding one of the methods of thermoplastic polymers joining. In this paper, the research was presented, which the aim was analysis of quality of joints obtained as a result of resistance welding of polypropylene pipes with diameter ø20 in the temperature range of 200÷230°C. To that end a Testo thermal imaging camera was used, flexural strength of the combined components was tested as well as the received weld was observed under a stereoscopic microscope. Conducted studies showed that the best results of joint are obtained during welding at 220°C and 230°C, while lower temperatures did not fully perform their function during the process of joining the pipe elements.

Keywords: polypropylene pipes, socket fusion welding, thermovision, bending strength, microscopic analysis

1. Introduction

Polymer materials, due to their attractive mechanical, chemical, thermal or technological properties, supplant classic, metal, construction materials in many applications, creating new possibilities of their use in practically every area of life. This is also facilitated by the methods of their modification and improvement, including techniques of joining elements made of polymer materials, which, due to their rather complex, variable properties with temperature, are not easy processes. In addition, the choice of joining technique depends not only on the structure and thermal properties of the materials, but also on the used additives. In the case of thermoplastics, such as polypropylene PP, polyethylene PE, welding and pressure welding methods are mainly used (similar to metals). In turn, chemically hardenable and thermosetting materials or some of thermoplastic polymers (e.g. PVC, PMMA) are joined by gluing and laminating [1-4].

In the case of polypropylene pipe installations, socket fusion (resistance) welding methods are sometimes used. This process involves connecting elements as a result of plasticising and melting the material at the place of their connection with subsequent application of pressure. This takes place in the outer layers of joined materials, which under the influence of heat pass into plastic, then liquid state, through which the macromolecules of plastics intertwine, that improves mutual pressure. In the case of the above mentioned socket fusion welding, electric heating elements and socket fusion fittings suitably matched to the ends of the pipes are used for heating, and this technique requires precise control of the process parameters, thereby guaranteeing a proper, durable and aesthetic connection. The effects of the connection depend on the process temperature (close to the melting point of the material), clamping force exerted on the joined elements, welding time and cooling conditions and time [1,5-7]. These determinatives make the welding process be not fully understood, hence requires more analyses, e.g. based on scanning acoustic microscopy allowing to detect dissidences and assess quality of obtained welds without sample destruction [8].

Moreover, with regard to exploration of the temperature range, in which materials should be combined to obtain the best, most optimal connection for a given case, also thermovision is applied. This technology is based on the principle of detecting infrared radiation emitted by a given object, which is then converted by specialized systems into an electrical signal and transformed into so-called thermogram – thermal image [9-10]. Thermal imaging methods have found many applications in the modern world, both in commercial and industrial areas, including as a matter of fire protection, where this type of devices support life-saving actions through evaluation of fire situations, searching for fire victims or fire sources [11]. In turn, in energy technology and construction thermovision cameras allow to verify the

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right working of devices of mains electricity or to assess various buildings condition, detecting their possible defects or seepages [12-13]. Also medicine and physiotherapy benefit from this technology e.g. at diagnosis of inflammations, degenerative or cancerous changes of various tissues and organs or evaluation of effectivity of physiotherapeutic treatments [9-10,14]. In the case of industry, thermovision method is primarily applied during machines and devices diagnosis, services or maintenance, but it also supports research procedures and machining processing and manufacturing processes. For example, in the paper [15] authors have applied thermal imaging camera during turning to check the dependence between turning parameters and temperature in cutting zone, which affect material properties as well as tool wear and durability. In turn, in articles [16-17] it has shown the use of thermovision tests as a diagnostic tool in the processing of polymer materials, allowing for subsequent modifications and optimization of the injection mould. Whereas, in the works [18-19], the authors have presented the use of thermovision analysis to assess the quality of welded joints and to monitor distribution heat during butt welding, while at paper [20] scientists used thermovision tests to assess influence of flash removal parameters on selected properties of friction or resistance welded joints. Therefore, it can be seen that thermovision has found many applications in industry.

The issues related to joining polymer materials are more complex nowadays than they were a dozen years ago, which is related to the improving their (not only mechanical) properties, development of processing methods or new, better composite materials. Hence it poses new challenges in the field of e.g. joining methods by welding polymers. It in turn determines the increase in the amount of research on modernising these welding methods to make them more effective and more durable, which example is application of thermovision in polymer processing for assessment of manufacturing processes as well as the produced components and their quality [18-20].

2. Research Material and Methods

The aim of the conducted research was to analyse the quality of joints made by resistance (socket fusion or polyfusion) welding. Tested samples were obtained from 170 mm long-cut polypropylene tubes (which are made from PP-R according to standard PN-EN ISO 15874-2:2013) with a diameter of ø20 mm and a wall thickness of 3.4 mm, joined by means of couplers (also polypropylene PP-R with length of 36 mm and diameter of ø20 mm), as shown in Fig. 1. In addition, the ends of the specimens have been milled with a special peeler in order to remove the outer layer of ending pipe parts and to fit them to the coupler. In turn, in Fig. 2 a part of connection of polypropylene tube with coupler which was obtained by means of socket fusion welding is presented.

The pressure welding process was carried out using M55905 welding machine from the Mar-Pol company with double insulation. In addition, with the object of avoiding the reflection

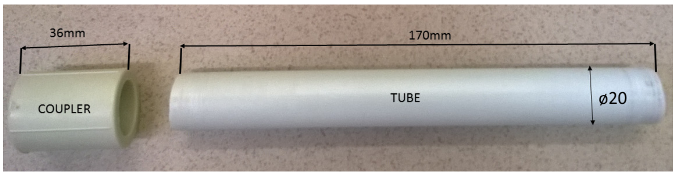

Fig. 1. Polypropylene components: tube after end milling and coupler fitted into a tube diameter

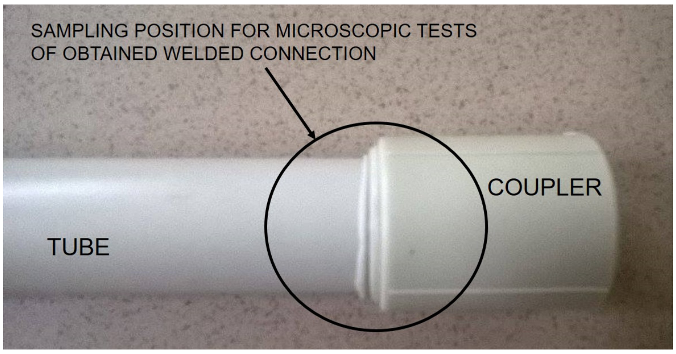

Fig. 2. Connection of polypropylene tube with coupler obtained by means of socket fusion welding

of infrared rays recorded by the thermal imaging camera, both the welding machine and the heating sockets (i.e. stem and sleeve) were lightly matted with abrasive paper before testing and then covered with a matting, heat-resistant preparation. In turn, the recording of temperature changes on the stem and heating sleeve of welding machine was possible thanks to the attached thermocouples. The welding process was carried out in the temperature range from 200 to 230°C during 20 seconds – from the moment of placing the tube and couplers on the heating sockets. These elements are heated to set temperature (which caused plasticising of their surfaces) and then mechanically joined together by means of a press fit (i.e. sliding pipe endings into coupler slots). However, the values of the force of coupling the tubes with the coupler may have been unequal due to the impossibility of measuring this parameter.

Then, the analysis of temperature changes in the joint obtained as a result of socket fusion welding was carried out using a Testo 890 model thermovision camera, whereby thanks to the IRSoft program it was possible to make temperature profiles. Device of this type is aimed to register the intensity of radiation in the infrared part of electromagnetic spectrum and to convert it into a visible image. This camera detects infrared radiation, which can be emitted by a given object, e.g. building, equipment, machine or human and then it is focused by optics of this device. The detector convert obtained data into an electric signal, which is in turn processed into an image, i.e. thermogram that can be viewed on a standard video monitor or LCD screen. Thanks to this, it is possible to get to know about the temperature distribution on tested objects, which is presented in the form of coloured isotherms. This enables monitoring and diagnosis of the conditions of studied objects as well as helps to identify occurring problems or defects in various processes [9-10,13,21-22].

After the welding process and complete cooling of the joint, the analysis was carried out to assess the bending strength of the joint. The tests were performed on a Zwick/Roell Z020 testing machine with an installed three-point bending fixture according to PN-EN ISO 178 standard [21]. This test consists of supporting the sample at its ends and loading it perpendicularly to the longitudinal axis of the tested material, whereby the distance of the support points is strictly defined and the load is applied symmetrically to them (Fig. 3). The evaluation of bending strength characteristics is only applied to brittle materials that crack during the test. At the moment of bending under the action of load, the upper surface of the specimen decreases and its lower surface lengthens, which is caused by the occurrence of compressive stresses in the upper part of the sample and tensile stresses in its lower part. During bending, the supports were 200 mm apart and the thickness and width of the samples measured on the coupler was 27 mm.

The tests were also conducted on Nikon SMZ800 stereoscopic microscope with the aim of a complement the analysis of the quality of welded joints made under different temperature conditions. These studies helped with assessment of the joint appearance in its cross-section for samples welded at different temperatures. The tested samples were prepared by cutting the tube connected to the coupler in the longitudinal direction to the axis of the studied tube. Then, the cut parts were sprayed with a red Diffu-Therm penetrant intended to surface non-destructive tests with aim of detecting connection defects. This treatment caused the coupler material to turn pink, whereby the pipe material did not change colour.

3. Results and discussion

3.1. Analysis of temperature distribution by means of thermal imaging camera

As mentioned above, the studies with using thermal imaging camera were carried out to analyse the quality of joints made by socket fusion welding at various welding temperatures. The results of these test are thermograms and graphs of temperature distributions. For example, Fig. 4 shows the temperature distribution graphs recorded during the pressure welding of polypropylene pipes at preset welding machine temperatures, whereby the red colour indicates the temperature distribution on the heating pin (stem) and the blue colour indicates the temperature distribution on the heating sleeve.

Analysing the results obtained during welding the pipe at 200°C (Fig. 4a), it can be concluded that the temperature value of the heating pin is approximately 15°C lower than the value on the heating sleeve, whereby throughout the entire welding process, the temperature values remained at a similar level. Only after the process was completed the values recorded on the heating pin start to decrease sharply. In turn, in the case of welding pipes at a preset temperature of 210°C (Fig. 4b), it can be observed that the maximum temperature difference between the heating sockets was about 5°C, with the heating sleeve temperature remaining lower than the heating stem temperature. On the other hand during welding at the preset temperature of 220°C on a welding machine (Fig. 4c) the temperature difference between the heating sockets was 8°C, both temperatures were decreasing, but its value on the heating pin was higher. A temporary drop in the value on the curve representing temperature changes of the heating pin may be also noticed, which may be caused by the movement of the thermocouple. In turn, when pipes were welded at 230°C (Fig. 4d) the difference in values on the stem and heating sleeve was 18°C. It can be observed that the temperature values recorded by thermocouples are slightly, but gradually decreasing in the welding time.

In the next step of these studies with using thermovision camera, the thermograms pictured temperature distributions on obtained welds at various processing parameters as well as showed changes of temperature values during cooling the welded joint were received. For example, Table 1 shows the maximum values of the joint temperatures after welding pipes with ø20 diameter at the given temperatures.

The weld temperature after welding at the set temperature of 200°C has reached a maximum of about 102°C. During the first 30 seconds it dropped by 19°C, and after the next minute

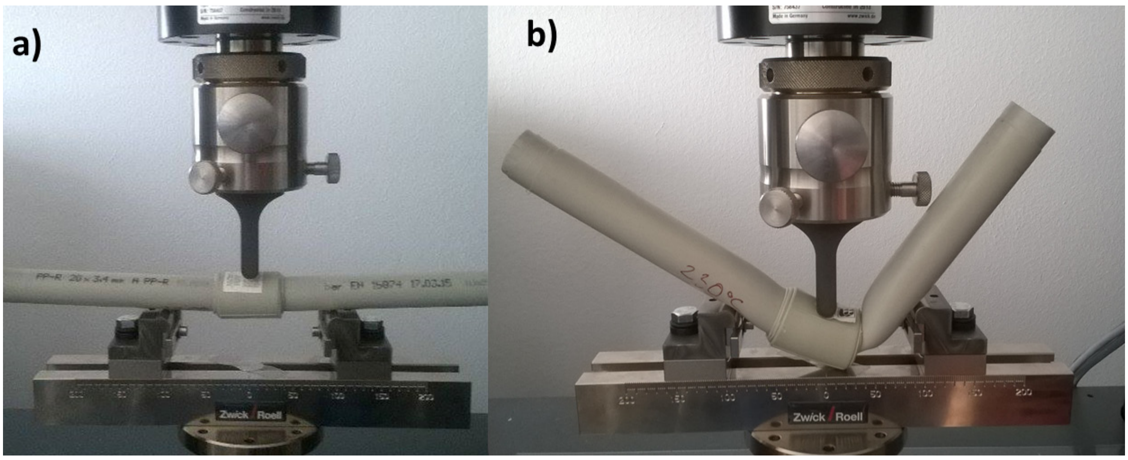

Fig. 3. Three-point bending test: starting position of sample (a) and position of sample at ending stage of test (b)

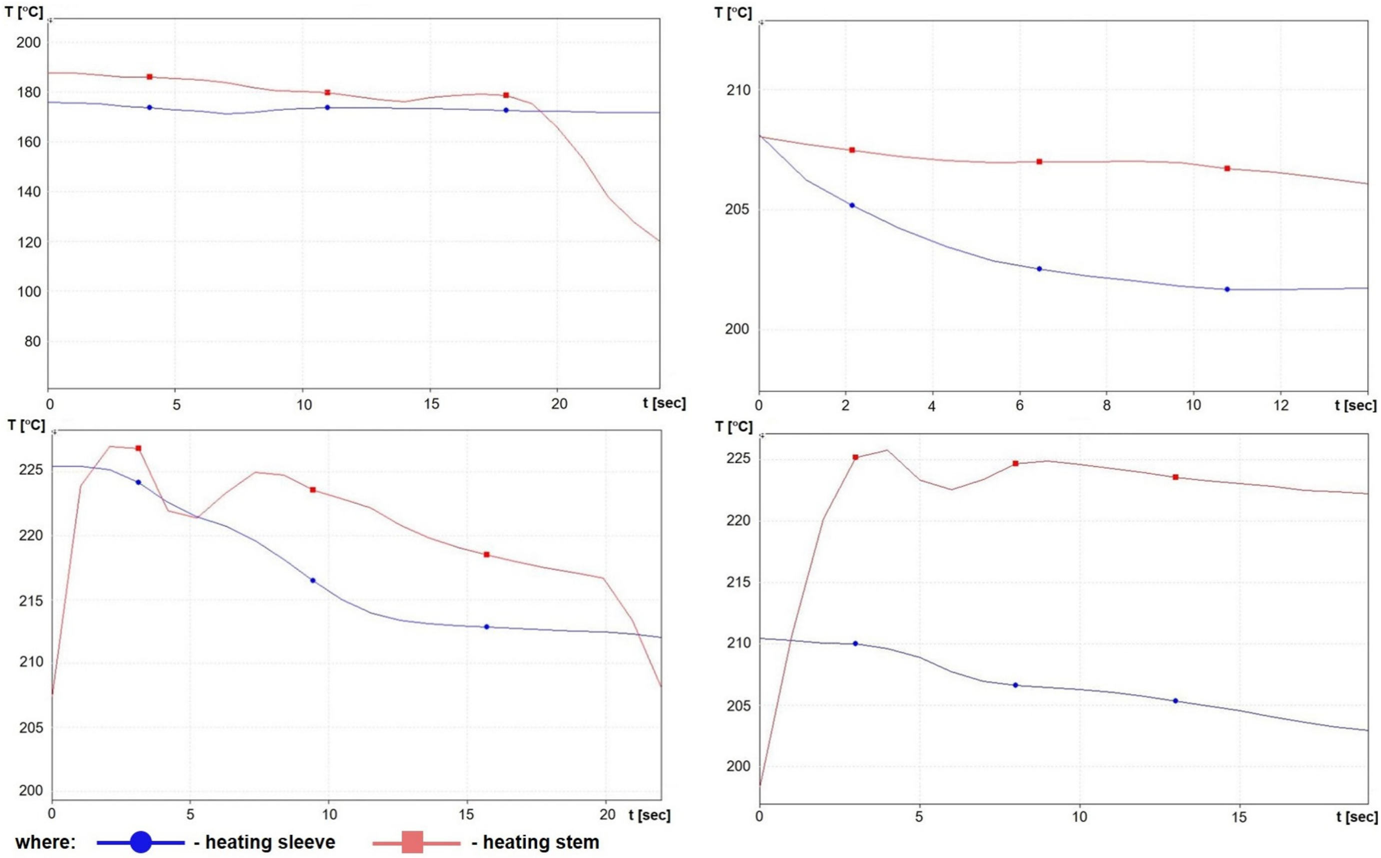

Fig. 4. Temperature distributions recorded by thermocouples on heating stem and sleeve during pressure welding of pipes at preset temperature of: (a) 200°C, (b) 210°C, (c) 220°C, (d) 230°C

TABLE 1

Maximum joint temperature values after welding the polypropylene tubes at the set temperatures

Time after welding, min	Joint temperature after welding at 200 °C, °C	Joint temperature after welding at 210 °C, °C	Joint temperature after welding at 220 °C, °C	Joint temperature after welding at 230 °C, °C
0	102	118	121.5	114.5
0.5	83	100.5	105	102.5
1	72	84.5	85	83.5
2	63.5	71	73.5	71.5
4	52.5	59	60.5	59.5
6	45	51	52.5	51.5
8	41.5	44.5	46.5	46
10	36.5	40.5	42.5	42.5
12	34	36.5	39	38
14	33	34.5	36	35.5
16	30.5	32	32	34.5

by an average of 11°C, whereby the cooling time of the samples to 30°C was about 16 minutes. In Fig. 5, it can be seen that the temperature of the material at the joint is much higher than that of the other, farther parts of this connection. In turn, thanks to the temperature profile obtained from the thermal imaging camera, it can be observed that the maximum temperature value at the joint was 103.4°C, while in the part of coupler it was about 70°C. After 30 seconds from the welding process, it can be also seen that the weld has cooled down quickly whereas the temperature of the coupler has not changed. Subsequent thermovision images show that the temperature distribution has become more and more even in process of time until the working surface temperature equals the ambient temperature after 16 minutes.

In the case of welding pipes at 210°C, the weld temperature just after this process was about 118°C, while after 30 seconds it dropped by approx. 20°C, reaching the value of 89°C after a minute. In turn, after 16 minutes, the temperature to which the fitting was cooled was 32°C. Analysis of the thermovision image together with the temperature profile immediately after the welding process (Fig. 6) allows to state that the increased temperature values are only related to places which were in contact with the surfaces of the heating sockets. In this case the maximum temperature recorded by the thermal imaging camera was 120.7°C. The following thermograms showed the situation when an elevated temperature goes beyond the working surface and the highest temperature range moves towards the coupler, matching the joint temperature. It can also be observed that the highest temperature value is located in the upper part of the coupler, which may be caused by heat transfer from the lower part of the fitting to the ground. Analysis of the temperature profiles shows that in process of time the temperature values start to distribute more evenly over the length of the pipe and coupler to reach value of 32°C after 16 minutes.

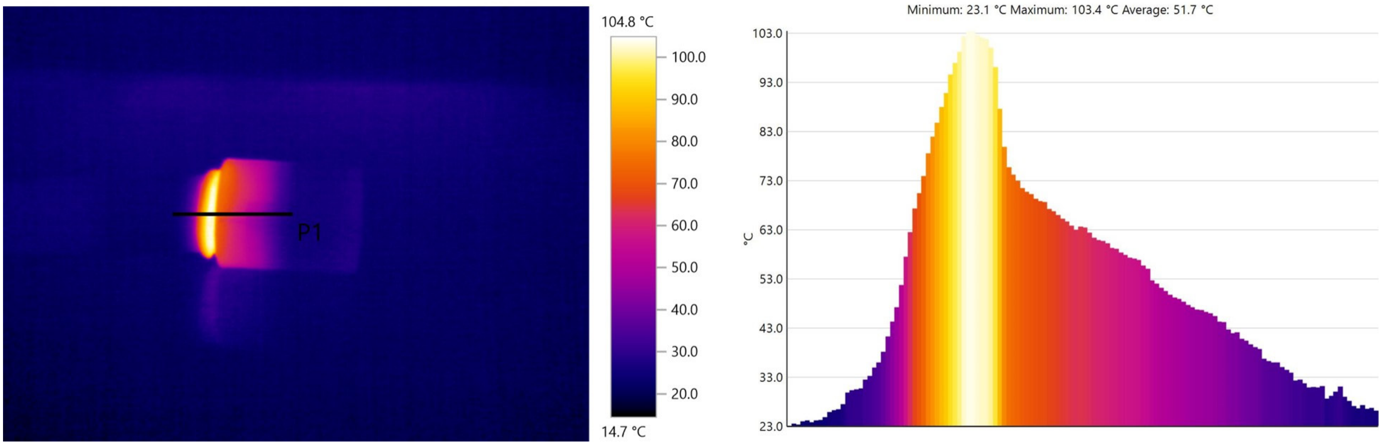

Fig. 5. Thermogram of the welded joint and temperature profile at the set temperature of 200°C just after welding

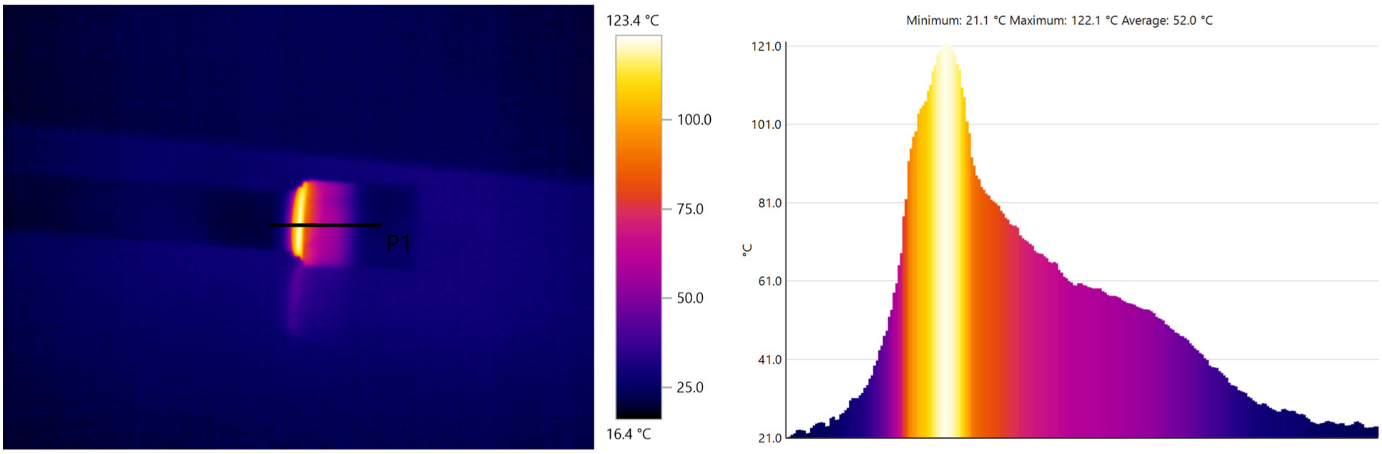

Fig. 6. Thermogram of the welded joint and temperature profile at the set temperature of 210°C just after welding

During welding the pipes at 220°C immediately after the process the temperature value was 121.5°C on average to drop by about 16°C after 30 seconds. Then, after subsequent two minutes, connection temperatures decreased by following 30°C. In this case, cooling to 32°C also took about 16 minutes. Figures taken with a thermal imaging camera directly after the welding process (Fig. 7) represent an image where only the working surfaces are heated immediately after the joining of elements and the maximum temperature is clearly indicated. After one minute, it can be observed that, in addition to the highest value at the connection between pipe and coupler, small sections of the components that did not have contact with the welding machine were also heated up. In the following minutes it is shown a gradual levelling out of the temperature range on the surface of the pipe and coupling unit, which was caused by heat transfer to lower temperature surfaces.

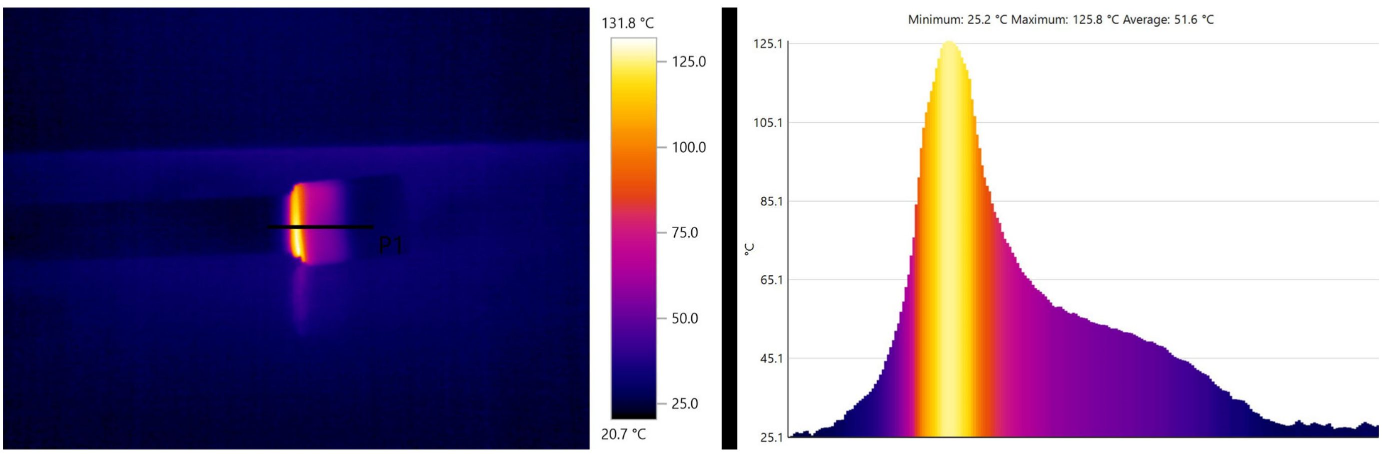

Fig. 7. Thermogram of the welded joint and temperature profile at the set temperature of 220°C just after welding

The maximum temperature during welding pipes at 230°C was 114°C on average and 30 seconds after this process, this value dropped by 12°C. On the other hand, the cooling time of the material to 32°C was longer than in previous tests and was 18 minutes. On the thermogram immediately after the welding process (Fig. 8) the place, where the welded sample reaches its maximum, is clearly visible. On the temperature profile it can be seen that the material is only heated on the working surface of the elements. In the following minutes, the heat was observed to move beyond the surfaces previously in contact with the welding machine. As with welding at lower temperatures, the area with the highest temperature is situated at the top of the coupler.

3.2. Analysis of strength properties of obtained welds during three-point bending test

Table 2 shows the results obtained during bending strength testing of pipes with a diameter of ø20. Analysing these results, it can be stated that the highest bending strength is found in a joint welded at a given temperature of 220°C, with a maximum value of 1990 N. In turn the lowest maximum force causing the break of specimen was found in components welded at 210°C. It can be observed that the flexural modulus of elasticity, similarly to the maximum force causing the sample to break, was the highest at 220°C (1340 MPa) and the lowest at 210°C, where it was equal 590 MPa. The results obtained during the test of the jointed pipes at lower temperatures show that the welds made at these temperatures do not show adequate strength characteristics. Hence on the basis of these tests it can be determined that the optimum temperature for a good quality welded joint is 220°C.

TABLE 2

Average results of bending strength tests of pipes welded at different temperatures

Pipe diameter, mm	Welding temperature, °C	Maximum force causing the sample breakage (averaged values), F_{fm}, N	Flexural modulus of elasticity, E_f, MPa
20	200	1960	1260
20	210	1940	590
20	220	1990	1340
20	230	1960	1300

3.3. Analysis of obtained welded joints with stereoscopic microscope

Fig. 9 and Fig. 10 show pictures of whole samples for tests made at different welding temperatures as well as pictures of welded joints. Studies with a stereoscopic microscope showed that at welding temperatures of 200°C and 210°C, the material subjected to the process did not merge thoroughly – at these temperatures the material did not melt and mix. Small polymer flashes can be observed at the ends of the pipes where they connect to the coupler. In turn, small air bubbles can be seen on the lines connecting the coupler to the pipe. However, the material behaved completely different at higher temperatures (220°C and 230°C). The microscopic images show that during the joining, the pipe material has been thoroughly bonded to the coupler material. The material from both welded elements has been mixed, hence no air bubbles are visible on the connecting lines. The point of flowing up of the polymer material is clearly visible at the ends of the pipes.

4. Conclusion

The bonding process is an important part of the processing of polymer materials, allowing to form elements with a structure impossible to obtain in a conventional way. Pressure welding of this material type is one of the basic methods of joining them. In this process thermal energy is supplied to the polyfusionally welded element, which result in plasticisation of that had a contact with the source of heat. It – in turn – allows to be connected with another element subjected to the same process. However, in connection with development of better materials, incl. composites and improvement of processing methods, this technology is

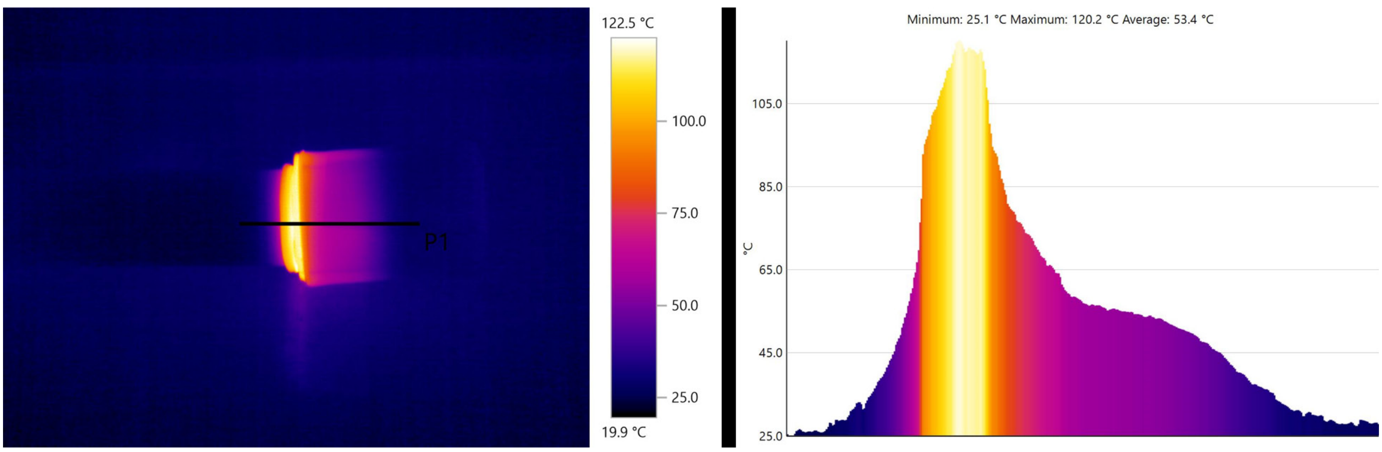

Fig. 8. Thermogram of the welded joint and temperature profile at the set temperature of 230°C just after welding

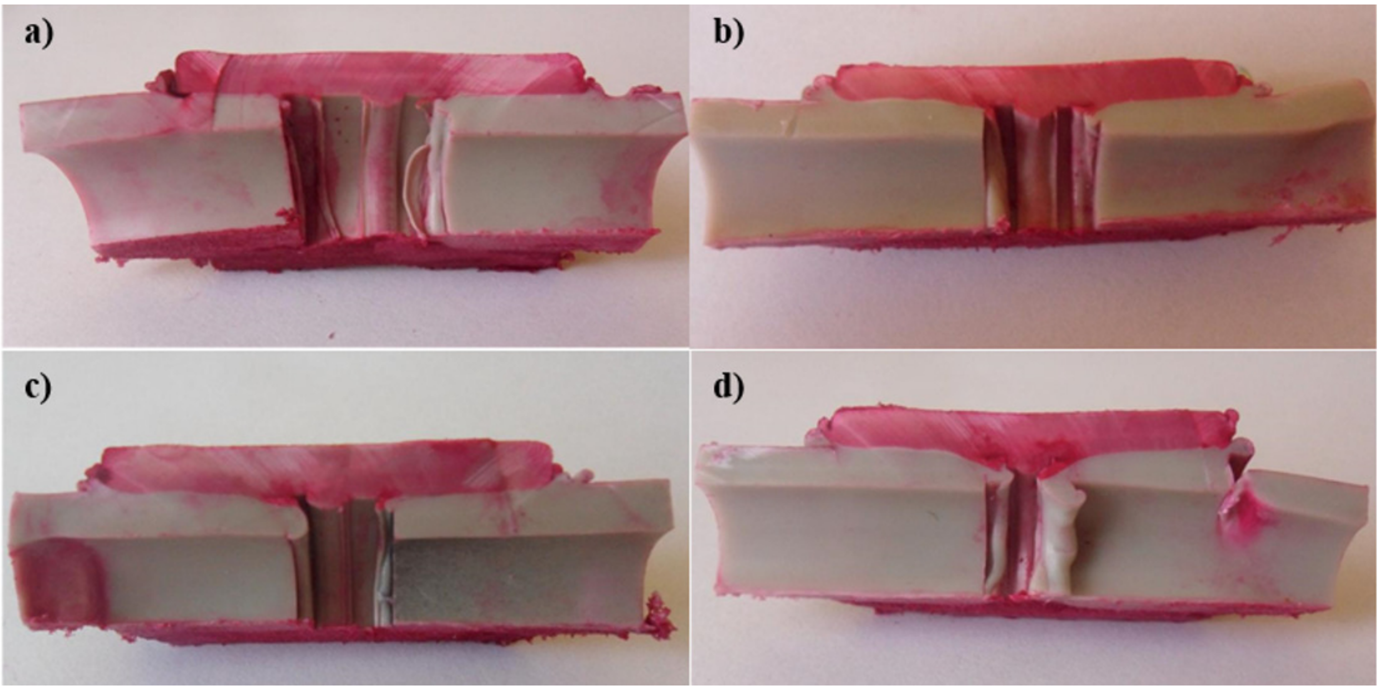

Fig. 9. Pictures of samples of a pipe welded with a coupler at temperature of: (a) 200°C, (b) 210°C, (c) 220°C, (d) 230°C for stereoscopic microscope research

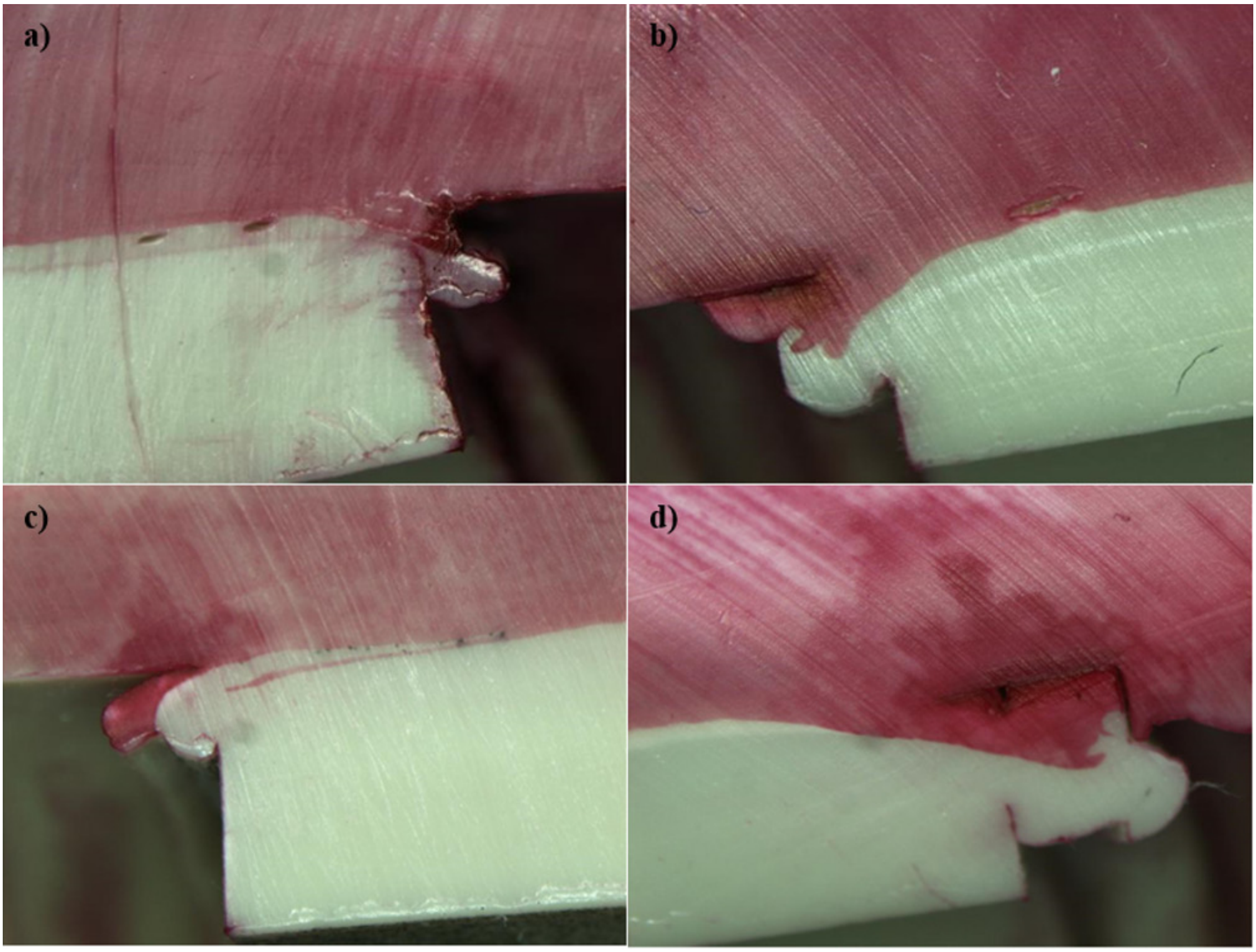

Fig. 10. Pictures of a joint welded at: (a) 200°C, (b) 210°C, (c) 220°C, (d) 230°C obtained as a result of the stereoscopic microscope research

also refined e.g. through application of thermovision both in the assessment of the process itself and manufactured components and their quality.

Due to the above the research has been conducted, which was aimed at analysis of temperature distribution of polypropylene pipe connecting with coupler by socket fusion welding process. Studies with using thermal imaging camera showed how temperature welding (from range 200÷230°C) affects the quality of obtained joining and how its value changed in several places of the combined elements in the process of time. This thermographic analysis showed that immediately after the welding process, the temperature maximum occurs in places, where the tested elements contact the working surfaces of the welding machine. In addition, it was observed that higher temperatures involve the upper part of this component, which was caused by heat transfer from its lower part to the ground. In the process of time, a progressive equalising of temperature values on the pipe and coupler surfaces was noticed. However, in the case of welding at 230°C, the process of cooling the element took about 2 minutes longer than in the case of other tests. Generally, these studies did not show any significant dependence of the welding temperature set on the machine and the temperature obtained at the place of weld.

In addition, subsequent tests related to the bending strength of a welded joint showed that the force causing the breaking of sample continuity, i. e. its rupture for specimens welded at temperature of 200°C and 220°C was higher than those welded at 210°C and 230°C. The situation was similar for the obtained flexural modulus of elasticity values. The analysis of the obtained results showed that the highest bending strength (1990 N) and the highest value of the flexural modulus of elasticity (1340 MPa) are characterized by a joint welded at 220°C, while the welds made at lower temperatures do not show adequate strength characteristics. Therefore, it was concluded that the optimum welding temperature for a good quality of welded joint is 220°C.

On the other hand, from the observations on the stereoscopic microscope it can be concluded that in the case of samples welded at a temperature of 220°C and 230°C obtained joints of pipe material with coupler material are more accurate than those welded at lower temperatures (200°C and 210°C), where small polymer flashes as well as and air bubbles could be seen at the point of contact of both elements. These differences were caused by the fact that the material in these parameters was not completely melted and mixed.

Based on the results of the carried out tests, it can be concluded that resistance welding of polypropylene elements welded at 220°C and 230°C gives optimal results due to both thermal, mechanical and visual properties of the obtained joint. Lower process temperatures do not fulfil well enough tasks during joining polymer materials.

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