

Strength of Assembly Butt Joints of Plastic Pipes

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ABSTRACT

The aim of the study was to compare the welded and adhesive joints made of polypropylene pipes. The pipes were butt jointed. Two pipe diameters were used: $\varnothing 20$ mm and $\varnothing 25$ mm. The welded joints were made by hot gas welding, while the adhesive joints were made by two epoxy adhesive compositions. The base for both compositions was Epidian 6 epoxy resin, which was mixed with IDA and TFF curing agents in the recommended quantitative ratios. The experimental tests consisted in determination and comparison of the strength properties of the made joints; therefore, the analyzed joints were subjected to the destructive strength tests, which determined their tensile strength in accordance with the ISO 527–1 standard. On the basis of the obtained results, it was observed that welded joints obtained the highest average strength. The lowest strength was characteristic for the adhesive joints made with Epidian 6/TFF/100:27 adhesive. The obtained results were subjected to a statistical analysis, which showed that the strength of $\varnothing 20$ mm diameter pipe joints did not differ significantly from the strength of $\varnothing 25$ mm diameter pipe joints, comparing the results for each type of joint with the assumed level of confidence $\alpha = 0.05$.

Keywords: adhesive, welding, sleeve joints, permanent joints

INTRODUCTION

Joining the elements is an indispensable stage in the execution of many constructions. This is possible due to the assembly connections. Such connections are divided into permanent and temporary joints [1, 2, 7]. The permanent joints are those that cannot be disassembled in any way other than the complete destruction of the joint. The temporary bonds can be assembled and disassembled several times. The connections made in the process of adhesive bonding, welding, riveting or soldering belong to the group of inseparable connections, whereas inlet, snap-in or threaded connections belong to temporary connections.

Cohesion connections are being increasingly often used in various areas of technology. The development of well-known technologies and the introduction of new technologies in this field allow not only the combination of different metallic materials but also of ceramic and plastic materials [1, 29]. An important aspect in the creation of the

structures with bonded elements is their strength. The welded joints are among the best connections in this respect. There are a number of welding methods used in a variety of structures [5]. The great advantage of these connections is that they do not take too much time and are relatively easy to complete. However, the costs associated with the purchase of the welding equipment and consumables make it an expensive method [14, 30].

Frequently, it is necessary to combine the elements made of dissimilar materials. In such situations, adhesives play an important role. Joining the elements by means of adhesives has been known for a long time; however, it is only recently that it has started being used in the construction process and is a valuable addition to the existing methods of joining [22]. Adhesives have a wide range of applications in engineering, automotive, aviation, construction, medical, light industry, as well as in various areas of technology [4, 7]. The adhesive bonds are durable and have a much lighter structure than the welded bonds. They have a number

of advantages, such as corrosion resistance, sealing, vibration absorption and good insulating properties [27]. However, it should be noted that the cohesion connections made using different methods may have certain drawbacks and limitations, which may have a negative impact on the quality, strength and lifespan of the connection. Therefore, it is very important to choose the right method of joining and the accuracy of making the connections [24].

A comparison of the strength properties of butt welded and adhesive joints was presented in this paper. The joined elements were polypropylene pipes. The welding process was carried out by hot gas welding, while the adhesive joints were made with the use of two-component epoxy adhesive compositions. The experimental tests were carried out to determine which type of joints is more effective in terms of strength due to the bonding method.

METHODS OF RESEARCH

Material used in the studies

Plastics are increasingly used as basic construction materials, often being the only ones under given conditions. Their very wide variety in terms of structure and properties requires the knowledge of characteristic features before selection can be made.

Polypropylene (PP-R) pipes with a diameter of $\varnothing 20$ mm and $\varnothing 25$ mm were used for the experimental studies. The pipes were cut into 40 mm lengths. The edges of short pipes at the intersection were deburred and then, depending on the chosen method of assembly, their surface was subjected to appropriate treatments. The prepared samples were butt jointed.

Polypropylene (PP-R) is a thermoplastic material belonging to the group of olefin plastics. Owing to its properties and ease of processing, it can be subjected to bonding, welding, etc. It is characterized by corrosion resistance and low thermal conductivity; moreover, it does not react with water and its compounds [8, 28]. Table 1 shows the selected properties of polypropylene.

Polypropylene pipes are very popular and easily accessible, making them the most commonly used polymer pipes in many industries. Polypropylene is mainly used in the chemical, pharmaceutical, electrotechnical, electronic and

automotive industries. The PP-R pipes are also often used in hydraulic systems of hot and cold water, central heating, as well as sewage, drainage and protective systems [6, 10, 21].

Welded joints

During the research, butt welded joints were made. The strength of the welded joints depends not only on the welded material itself, but is mainly related to a number of other factors resulting from the adopted welding technology. Hot gas welding was used to make the joints. The welding of polymeric materials is defined as the process of hot joining thermoplastic elements by plasticizing and melting their edges without exerting pressure [17, 31]. The most important is the process of welding in a hot gas stream, using welding rods acting as a bond. When selecting this material, the following basic principles should be accounted for: similar chemical compositions of the bonded material and the bond, the mechanical properties of the bond at least equal to those of the parent material. In this type of welding, the hot gas stream is usually air or – less frequently – nitrogen and carbon dioxide. The use of nitrogen and carbon dioxide protects plastics against excessive oxidation at elevated temperatures. Excessive oxidation may occur during air application, especially when welding the plastics that are relatively easily oxidized.

The process of welding polypropylene pipes was carried out using a Yihua 992DA+ plastic welding machine. The basic parameters of gas leaving the burner were: temperature – 260°C, pressure – 0.05 MPa. The material used as a binder is of the same type as the combined material,

Table 1. Recommended operating parameters used in testing materials [12, 13, 20]

Properties	Value	Unit
Density	0.90–0.91	g/cm ³
Melting point of crystallites	69–75	°C
Glass transition temperature	-35	°C
Vicat softening temperature	135–150	°C
Melting point	160–165	°C
Tensile strength	1–3.6 · 10 ⁷	Pa
Breaking strength	3–4 · 10 ⁷	Pa
Tensile elongation	5–15	%
Elongation at break	500–700	%
Compressive strength	(0.7–1) · 10 ⁸	Pa
Specific heat at 23°C	1.92	J/(g·K)
Water absorption after 24h	0.03	%

i.e. polypropylene. The connections were made in accordance with the recommendations of experts [9, 14, 30]. The surfaces of the elements to be connected are chamfered at an angle of 30°. During the welding process, the weld was made in one continuous passage. A schematic of the welded connections is shown in Figure 1.

The welding process was carried out under workshop conditions, in a draught-free room at 23°C at 24% air humidity. In total, 10 butt welded polypropylene pipes with diameters of Ø20 mm and Ø25 mm each were made.

Adhesive joints

The adhesive joints are made by inserting a thin layer of adhesive, referred to as an adhesive joint, between the surfaces of the joined elements. Dynamic development and more frequent use of adhesive technology is associated with the production of modern adhesives with much better properties [7, 11, 18]. The adhesive process consists of a number of steps, the most important of which are [23]:

- surface preparation for adhesive bonding,
- selection of the type, components and preparation of the adhesive mass,
- surface coating with adhesive,
- connecting the bonded parts and exerting pressure on the final joint,

- hardening and conditioning of constitutional joints.

In these bonding processes, the surface preparation of bonded parts consisted in unfolding the surface as well as removing dust and other contaminants from it. The surface was developed by mechanical cleaning with the use of an abrasive bulk tool in the form of the P120 grade abrasive paper, while the remaining impurities on the surface were removed at the stage of chemical cleaning with the use of an organic solvent, which was technical acetone.

Selection of the adhesive type and the method of bonding is determined by the type of bonded materials, working conditions of the joint and the required strength of the joint. Two epoxy adhesive compositions were used. Both compositions were based on the Epidian 6 epoxy resin, which was mixed with two different hardeners: IDA and TFF. Table 2 presents the composition and labelling of the adhesives. The stoichiometric ratio indicates the amount (in grams) of the hardener needed to cure 100 grams of resin.

Epidian 6 is an unmodified epoxy resin in the form of a viscous liquid with the consistency of a thick syrup and a light yellow colour. It is used to prepare an adhesive for cold bonding of materials such as metal, polymer materials, glass, porcelain, basalt, stoneware, etc. In addition, it is

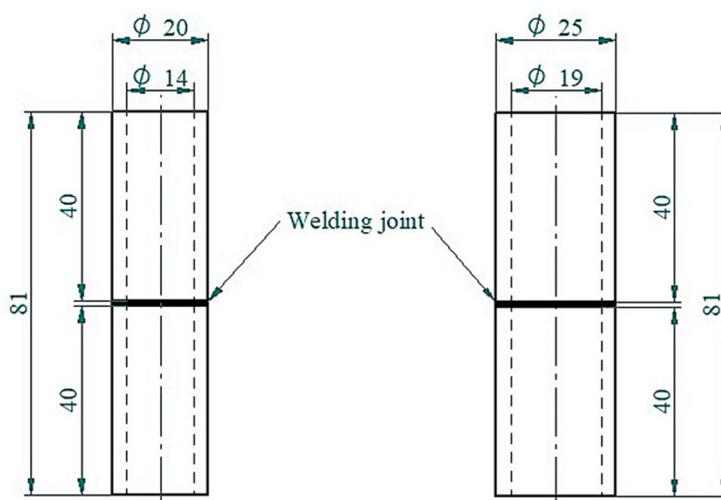


Fig. 1. Scheme of a butt welded joint made of polypropylene pipes with a diameter Ø20 mm and Ø25 mm

Table 2. Composition of epoxy adhesives used in studies

No.	Epoxy resin	Curing agent	Stoichiometric ratio	Labelling
1	Epidian 6	IDA	100:50	Epidian 6/IDA/100:50
2	Epidian 6	TFF	100:27	Epidina 6/TFF/100:27

also used to manufacture the linings for chemical-resistant tanks, fibre-reinforced pipes and mastics used in electrical engineering and electronics. The properties of this epoxy resin are presented in Table 3.

The IDA and TFF curing agents were used to harden the Epidian 6 resin. The IDA hardener is used mainly for hardening of floor masses. It enables to obtain a surface with perfect smoothness and high gloss. These surfaces also have good mechanical and chemically resistant properties. The IDA hardener can also be used to harden low molecular weight epoxy resins [15]. The gelation time of the IDA hardener mixed with Epidian 6 resin is about 40 minutes at 20°C. The TFF hardener is used for hardening the epoxy compositions intended for the building industry, where work is carried out under the conditions of low temperature, often at high humidity. The good chemical resistance of such compositions in many aggressive environments qualifies the TFF hardener for the hardening of anti-corrosive linings in industry. The positive hygienic rating allows it to be used for various types of epoxy coatings in public utility rooms and in the food industry [16]. The gelation time of the Epidian 6 composition with the TFF hardener at 20°C is 17 minutes. Table 4 shows the properties of the hardeners used in the research.

The adhesive compositions were prepared directly before the process of bonding. The components of the mixtures were carefully weighed using a laboratory scale and then mixed with a mechanical mixer equipped with a propeller mixer. The mixing process with the speed of 460 rpm lasted 2 minutes. Next, the adhesive compositions

were deaerated for 2 minutes in order to remove the gas bubbles formed as a result of mixing the components. The finished adhesive compositions were applied to the surfaces to be bonded using a roller for adhesive application, which enabled to achieve a homogeneous thickness of the joint across the entire adhesive surface. In the next stage, the elements were joined together. The joints thus formed were subjected to a single-step curing process at ambient temperature at a load of 1 kg. The total curing time was 7 days. In order to avoid deformation of the joints, a special pipe holder was used after the assembly of the parts to be joined. This fixture prevented the surfaces to be joined from shifting relative to each other at the point of bonding, thus facilitating the axis alignment of the structure. Figure 2 shows the diagrams of adhesive joints made during the research.

The entire process of adhesive bonding, including surface preparation, was carried out under laboratory conditions at a temperature of $23 \pm 2^\circ\text{C}$ and an air humidity of $28 \pm 2\%$. A total of 40 adhesive bonds were made during the experimental tests. For each diameter and each type of adhesive, 10 adhesive bonds were made.

Strength tests

After the assumed curing time, the welded and adhesive joints were exposed to the destructive strength tests on a Zwick / Roell Z150 testing machine. Testing was performed in accordance with ISO 527-1, with a preload of 20 N and a test speed of 5 mm/min. A special gripping fixture was used to secure the specimens to the jaws of the testing machine [25]. The tensile strength of the obtained joints could be determined by means of strength tests.

RESULTS OF STRENGTH TESTS

The comparison of the results of strength tests taking into account the diameter of the jointed pipes is presented in Figure 3.

Table 3. Properties of epoxy resin Epidian 6 [3, 26]

Property	Value	Unit
Boiling point	>200	°C
Flash point	>200	°C
Self-ignition temperature	>500	°C
Epoxy equivalent	185 – 196	-
Epoxy number	0.51 – 0.54	mol/100 g
Density at 20°C	1.17	g/cm ³
Viscosity at 25°C	10 000 – 15 000	mPas

Table 4. Properties of the hardeners used in the tests [15, 16, 19]

Property	IDA curent agent	TFF curent agent
Amine number	200 – 350 mg KOH/g	500 – 700 mg KOH/g
Density at 20°C	1.01 – 1.03 g/cm ³	1.15 – 1.20 g/cm ³
Viscosity at 25°C	150 – 300 mPas	Max. 10 000 mPas

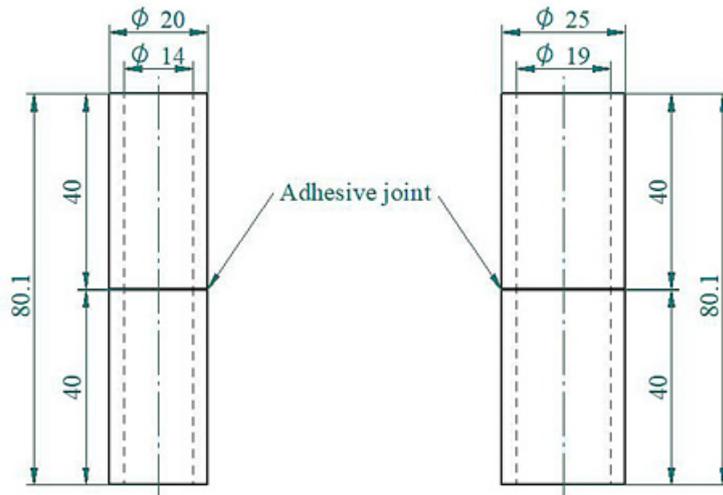


Fig. 2. Scheme of a butt adhesive joint made of polypropylene pipes with a diameter Ø20 mm and Ø25 mm

On the basis of the presented test results, it can be observed that the welded joints achieved the highest average strength – for the joints of the samples of ø20 mm diameter, the strength of 7.3 MPa was obtained, while for the joints of the samples of ø25 mm diameter, the average strength was 6.8 MPa. The worst results were obtained for the adhesive bonds made with Epidian 6/TFF/100:27. For the samples with the diameter of ø20 mm, the strength was 1.9 MPa and for larger samples with diameter of ø25 mm – 2.1 MPa. It should be noted that the highest repeatability of the results was obtained for the welded joints. The process of adhesive bonding with the Epidian 6/TFF/100:27 adhesive composition turned out to be the least stable, estimating the repeatability of the obtained results. The standard deviation value was 0.3 MPa (for samples of ø20 mm diameter) and 0.45 MPa (for

samples of ø25 mm diameter), which constitutes 16% and 22% of their average strength.

Taking into account the diameters of the parts to be joined, the differences between the results obtained for the various methods of assembling the connections are small. The best way to illustrate this is to use the interaction diagram in Figure 4, which shows that the distribution of results including the joining method is the same for both samples with a diameter of ø20 mm and those with a larger diameter of ø25 mm.

The strength of assembly connections is an important criterion for the assessment of such connections. However, in order to enable a comprehensive assessment of the connections obtained, it is necessary to carry out a statistical analysis of the results obtained. The assumption ($p > \alpha$) of distribution normality (Shapiro-Wilk test) and variance homogeneity (Levene test)

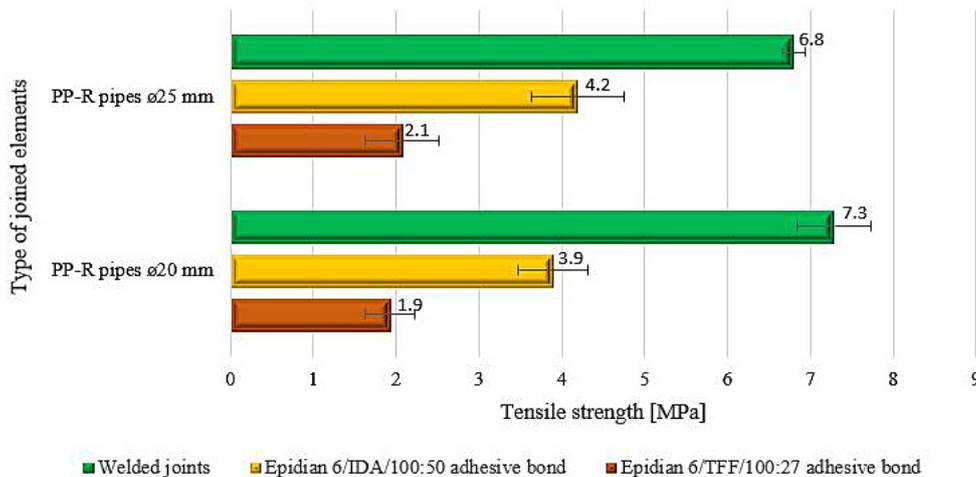


Fig. 3. Tensile strength of butt welded and adhesive joints of PP-R pipes

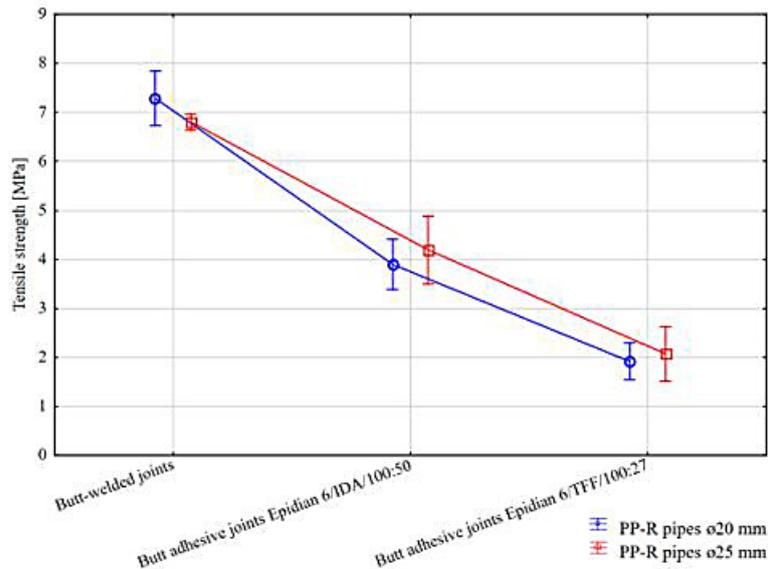


Fig. 4. Interaction diagram including assembly method and dimensions of the joined PP-R pipes

with the assumed confidence level $\alpha = 0.05$ was fulfilled. The results of these tests are presented in Tables 5 and 6. Therefore, parametric tests were used in the further stages of statistical analysis.

A Tukey RIR test was carried out to determine which type of connection is more advantageous in terms of strength and whether the differences are significant at the assumed materiality level $\alpha = 0,05$. The results of this test are presented in Table 7.

On the basis of the results obtained, it can be observed that there are no significant differences between the pipes joints of different diameters made with particular methods of joining at the assumed level of significance $\alpha = 0.05$. However, significant differences occur between the applied methods of joint making, i.e. the strength of welded joints of 20 mm diameter pipes does not

differ significantly from the strength of the welded joints of 25 mm diameter pipes, but they differ from the strength of adhesive joints made with adhesive compositions Epidian 6/IDA/100:50 and Epidian 6/TFF/100:27. The situation is similar in the case of adhesive joints made with both adhesives.

CONCLUSIONS

In the case of plastic structures, it is worth carefully considering the choice of assembly method because, as shown in the studies, the appropriate choice of technology has a significant impact on the results. The aim of the study was to compare the strength properties of butt welded joints and adhesive polypropylene pipes.

Table 5. Results of the Shapiro-Wilk normality test

Type of joint		Shapiro-Wilk statistics W	Probability level p	Normal distribution
Butt-welded joints	PP-R pipes 20 mm	0.968859	0.867884	Yes
	PP-R pipes 25 mm	0.909967	0.467393	Yes
Butt adhesive joints Epidian 6/IDA/100:50	PP-R pipes 20 mm	0.840582	0.166537	Yes
	PP-R pipes 25 mm	0.832014	0.144029	Yes
Butt adhesive joints Epidian 6/TFF/100:27	PP-R pipes 20 mm	0.944575	0.698438	Yes
	PP-R pipes 25 mm	0.862685	0.238050	Yes

Table 6. Levene test results of variance homogeneity

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Tensile strength [MPa]	0,380	5	0,077	0,859	24	0,036	2,125	0,097

Table 7. Tukey’s test results for reasonable significant differences

Type of joint		Average tensile strength	Butt-welded joints		Butt adhesive joints Epidian 6/IDA/100:50		Butt adhesive joints Epidian 6/TFF/100:27	
			PP-R pipes \varnothing 20 mm	PP-R pipes \varnothing 25 mm	PP-R pipes \varnothing 20 mm	PP-R pipes \varnothing 25 mm	PP-R pipes \varnothing 20 mm	PP-R pipes \varnothing 25 mm
Butt-welded joints	PP-R pipes \varnothing 20 mm	7.29		0.428122	0.000138	0.000138	0.000138	0.000138
	PP-R pipes \varnothing 25 mm	6.8	0.428122		0.000138	0.000138	0.000138	0.000138
Butt adhesive joints Epidian 6/IDA/100:50	PP-R pipes \varnothing 20 mm	3.89	0.000138	0.000138		0.860671	0.000138	0.000140
	PP-R pipes \varnothing 25 mm	4.19	0.000138	0.000138	0.860671		0.000138	0.000138
Butt adhesive joints Epidian 6/TFF/100:27	PP-R pipes \varnothing 20 mm	1.92	0.000138	0.000138	0.000138	0.000138		0.990927
	PP-R pipes \varnothing 25 mm	2.07	0.000138	0.000138	0.000140	0.000138	0.990927	

After experimental tests and analysis of the results, it was noticed that the highest average strength and the highest repeatability of the results were obtained in the case of welded joints. Among the adhesive bonds, higher strength was obtained for the bonds made with Epidian 6/IDA/100:50. Conversely, the lowest strength value was observed for the adhesive bonds made with Epidian 6/TFF/100:27 adhesive composition, and in this case the repeatability of the results was the lowest. It may prove that the process of welding polymeric materials is more stable in comparison to adhesive bonding. However, it should also be mentioned that the welding of polymer plastics is much more expensive compared to adhesive due to the necessary equipment and binders used in this process. Another explanation for the differences observed between the welded and adhesive bonds may be that polypropylene is a polyolefin polymeric material, a semi-crystalline thermoplastic and has a relatively high surface hardness. Therefore, it can be assumed that manual mechanical abrasive paper processing is not sufficient to prepare the surface of the bonded parts for the bonding process. The use of another method of developing the surface of a material such as polypropylene, e.g. by etching, could improve the strength properties of adhesive bonds. In addition, as mentioned above, the process of welding plastics is defined as the process of hot bonding thermoplastic elements by plasticizing and melting their edges, so that no other material than the parent material is introduced into the structure of such a bonding.

Moreover, it was observed that the size of the combined elements did not significantly influence the results obtained in this case. The strength of

\varnothing 20 mm pipe connections is not significantly different from the strength of \varnothing 25 mm pipe connections, comparing the results within each type of connection. Perhaps with wall pipes of different thicknesses the differences would be more significant.

The presented information may have a considerable impact on the design of welding and adhesive bonding technologies for polymeric materials. Other methods of surface preparation for the process of bonding polymeric materials are expected to be used in further studies..

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