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STAND FOR TESTS OF PIPES AND THEIR JOINTS UNDER CONDITIONS OF A PROGRAMMABLE INTERNAL PRESSURE VALUE AND VARIABLE TEMPERATURE

Key words: research stand, hydraulic components, thermocycling, pipes testing.

Abstract: Producers of hydraulic elements introduce new structural solutions and new materials. The aim of these activities is to increase the quality, reduce the costs, and shorten the assembly time of hydraulic elements. Consistently, with the requirements provided by the standards and technical specifications, the manufactured elements need to undergo tests of the resistance to variable temperatures and internal pressure loads. To reduce the time of tests and provide safety, the pressure applied to tested elements is higher than the load that they are exposed to while in regular operation. Additionally, the increased frequency of temperature changes is applied for the fluid, which flows through the system as well as a difference between the temperature of warm and cold fluid higher than in regular operation. Such tests are supposed to confirm the reliability of the tested structural solutions used in pipes and fittings and reveal problems connected with the impact of different types of materials and their combinations on hydraulic element systems. Commonly used tests stands are characterized by a large size and high energy needs. The aim of this study is to present the design and operation of a simple stand for tests of hydraulic elements and specimens whose internal surfaces are affected by the flow of fluid with higher pressures and variable temperatures. The analysed system is featured by smaller size, higher energy efficiency, and it needs less fluid for tests. Moreover, it enables the control of the test parameters in compliance with safety requirements.

Stanowisko do badań rur i ich połączeń w warunkach kontrolowanej wartości ciśnienia wewnętrznego i zmiennej temperatury

Słowa kluczowe: stanowisko badawcze, elementy hydrauliczne, termocykling, badania rur.

Streszczenie: Producenci elementów hydraulicznych wprowadzają nowe rozwiązania konstrukcyjne i materiały. Celem tych działań jest zwiększenie jakości, zmniejszenie kosztów oraz skrócenie czasu montażu elementów hydraulicznych. Zgodnie z zaleceniami norm oraz wymaganymi aprobatami technicznymi produkowane elementy muszą przejść badania odporności na zmienne temperatury i obciążenia wewnętrznym ciśnieniem. W celu skrócenia czasu trwania testów i zapewnienia bezpieczeństwa elementy poddawane są obciążeniu większym ciśnieniem niż podczas normalnej eksploatacji. Dodatkowo stosuje się zwiększoną częstotliwość zmian temperatury przepływającej cieczy przez układ oraz większą różnicę pomiędzy temperaturą cieczy ciepłej i zimnej, niż ma to miejsce w docelowych instalacjach. Tak prowadzone badania mają na celu potwierdzić niezawodność stosowanych rozwiązań konstrukcyjnych złączek oraz problemy związane z zastosowaniem różnych typów materiałów i ich kombinacji na elementy układów hydraulicznych. Obecnie stosowane stanowiska badawcze posiadają znaczne gabaryty i charakteryzują się dużym zużyciem energii. Celem pracy jest przedstawienie budowy i sposobu działania prostego w budowie stanowiska do badań elementów hydraulicznych i próbek poddawanych od wewnętrznej strony przepływowi cieczy o podwyższonym ciśnieniu i zmiennej temperaturze. Przedstawiony układ cechuje się mniejszymi gabarytami, mniejszym zapotrzebowaniem na energię i ciecz wykorzystywaną podczas badania. Ponadto umożliwia kontrolę parametrów badania przy zachowaniu wymogów bezpieczeństwa.

Introduction

The key element of water and heat supply systems for apartment buildings and public facilities or industrial facilities are pipelines. There are different technologies to be used for the construction of these systems They differ in terms of pipe types and their connection methods [1–4]. The solutions available on the market include mainly single layer, multilayer, and structured pipes. Single layer pipes can be made of different materials, most commonly metal alloys (steel, copper alloys) and polymers (polyvinyl materials and polyolefins) [5].

The group of polyvinyl materials mainly includes unplasticized polyvinyl chloride PVC, PVC-U, chlorinated polyvinyl chloride CPVC, and PVC-C, and the group of medium density includes polyolefin polyethylene PE-MD, high density polyolefin polyethylene PE-HD, high density cured polyethylene, PE-X, VPE, polypropylene PP, polypropylene homopolymer PP-H, polypropylene copolymer PP-Co, and polybutylene PB [6]. Multilayer pipes are made from different polymer and metal combinations [7].

Due to higher requirements regarding the functional qualities of pipes and their couplings (joints) as well as the optimization of their production and operation costs, they need to be constantly modified, including properties of the materials to be applied [7, 8]. Hence, it is necessary to introduce accelerated tests that will allow one to verify the properties of the applied materials, and the geometric features of pipes and their couplings (joints). This is of great importance; especially that life cycle of pipes is established to be 50 years.

Of particular importance in this respect are studies of pipes and connections of polymer pipes, including PE-X pipes with or without barrier layer(s) [9].

According to standards and technical specifications, the manufactured elements must be tested for variable temperatures and loads caused by internal pressure. To reduce the time of tests, the elements are loaded with a higher pressure than during regular operation. Additionally, the temperature of the operating fluid changes at a higher frequency than during operation. Moreover, the difference between the temperature of warm and cold fluid is higher than in the operating systems. Such tests are supposed to confirm the reliability of structural solutions used in pipes and their joints.

In this study, a stand is presented to be used for tests of pipe sections and their joints. Moreover, with the use of additional equipment, it is possible to tests specimens of materials used in pipes under conditions like those that occur in pipes.

1. Background

Tests of pipes under conditions of "thermocycling" are usually conducted with the use of individually arranged test systems. Currently, the test stands are quite large and are characterized by high energy consumption. The aim of the study is to show the structure and mode of operation of a new compact stand for tests of hydraulic elements and specimens of materials. This stand enables testing objects that are exposed to the impact of fluid flowing with higher pressures and are characterized by higher temperature differences. The presented system has smaller dimensions, it is more energy efficient, and it produces less noise and needs less fluid to be tested. Moreover, it provides the possibility of test parameter control in compliance with the safety requirements.

Connections in pipe systems made of thermoplastics are subjected to resistance tests for cyclic changes in temperature and pressure. The test method and requirements are included in the following standards: PN-EN 12293:2002 [10], ISO 19893:2011 [11], PN-EN 12295:2002 [12], ISO 19892:2011 [13], ISO 15875-5:2003 [14], ISO 10508:2006 [15]. The tightness of the tested set is checked during the tests and after its completion.

The method of testing pipes and their connections under cyclically variable temperature conditions consists in the alternating flow of hot and cold water under pressure.

The test is carried out for a certain number of cycles. The test equipment is usually a source of cold and hot water, equalizing valves, alternative equipment that affects the achievement of any change in water temperature in one minute, manometers, and pressure control devices. The test parameters, depending on the application class, are summarized in Table 1.

Table 1. The test parameters [14]

Parameter	Class 1	Class 2	Class 3	Class 4
Maximal design temperature, T_{max}, °C	80	80	70	90
Maximal test temperature, °C	90	90	80	95
Minimal test temperature, °C	20	20	20	20
Test pressure, bar	p_D	p_D	p_D	p_D
Number of cycles[a]	5000	5000	5000	5000

The notation is defined as follows: p_D – design pressure, respectively, 4, 6, 8, and10 bar

[a] – particular cycles: 15^{+1}_{0} min in maximal and 15^{+1}_{0} min in minimal testing temperature

The tests of the resistance of hydraulic connections to cyclic pressure changes are carried out at 23°C with the frequency of test cycles (30 ±5) cycles / min. The number of cycles is 10,000. Pressure values are shown in Table 2.

An example of a stand for testing the resistance of a set of thermoplastic pipes and fittings to cyclic temperature changes is presented in [16]. The device shown in Figure 1 contains two tanks to supply warm and cold fluid for testing. The fluids prepared in the tanks are alternately pumped by means of a pump of the tested hydraulic system. The fluid flow is directed by four cut off valves. The cut off valves are opened or shut by means of pneumatic servomotors controlled by a programmable logic controller (PLC).

Table 2. Pressure values [14]

Design pressure, bar	Upper limit of test pressure, bar	Lower limit of test pressure, bar
4	6	0.5
6	9	0.5
8	12	0.5
10	15	0.5

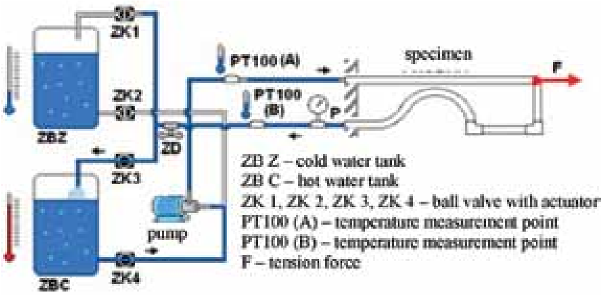

Fig. 1. Stand for testing the resistance of a set of thermoplastic pipes and fittings to cyclic temperature changes [16]

During the cold water circuit, the cold fluid tank outlet valve and the inlet valve of the warm fluid tank are open. The outlet valve of the warm fluid tank and the inlet valve to the cold fluid tank are closed. The fluid is pumped from the cold fluid tank through a specimen to the warm fluid tank. During the cycle with a warm fluid circuit, all valves are in the opposite positions. The pump moves the fluid from the warm fluid tank through the specimen to the cold fluid tank. Temperature and pressure are monitored throughout the test by means of two temperature sensors and a pressure converter. Pressure is controlled by a throttle. During the tests, force F is applied to the specimen and it is controlled and measured, and lateral stress is produced thanks to the design of the lateral chamber. A disadvantage of the stand is that cold fluid mixes with warm fluid. This requires the application of large tanks and involves significant energy losses due to the need to constantly heat the fluid in one tank and cool the fluid in the second tank.

Another recycling tester for plastic pipes was presented in [17]. Pipes and fittings are subjected to different pressures at variable temperatures, alternating between hot and cold water for a specified number of cycles. The fully digital pressure control system used in the system effectively prevents fluctuations in water pressure during accidental increases in both temperature and time. The testers are strong enough to withstand the high levels of tensile stresses and bending strains that occur when the specimen is subjected to temperature cycles. This equipment meets the requirements of international standards, such as ASTM F1335, ISO 15874, ISO15875, ISO 15876, and ISO 15877.

A similar solution was described in [18]. The system can be used to test the function of hot and cold water pipes made of PP, PE-X, PVC-C, and PB at a given pressure for 5000 cycles. The test set of pipes and fittings is subjected to a temperature cycle by the flow of water under pressure using hot and cold water alternately for a specified number of cycles. During the tests, the test object is held under tensile and bending stress by means of static clamps. During and after the tests, the tested tube and fittings assembly is monitored for leaks.

The tester complies with the following standards: ISO 10508, EN 12293, ISO 15874, ISO15875, ISO 15876, and ISO15877.

Other structural solutions are known as well. The devices described in Polish patents no. 160759 and 133973 are used for destruction of pipe specimens. A distinctive feature of these inventions is that pressure is applied through a pneumatic system and the destruction of the specimens leads to the closure of the fluid circulation maintaining the circulation of undestroyed specimens. In any of the two devices, there are no elements to enable temperature change in the fluid flowing through the tested system.

Current structural solutions do not enable the fluid flow through the tested specimen under higher pressures and variable temperatures or they are characterized by larger dimensions, because they need more fluid to be tested and they are less energy efficient.

Due to the necessity to minimize the size and noise, and according to the accepted assumption to reduce energy consumption, a decision was made to design a new test stand.

2. Stand description

A hydraulic part of the test stand (Fig. 2) includes a tank (1) with hydraulic fluid connected by a hose (2) with a pressure pump (3). On the hose (4), between pressure pump (3) and the three-way two position valve (5), there are a back-pressure valve (6), a safety valve (7), a release valve (8), the pressure switch of pressure pump (9), and a pipe tee (10). The hose (11) with the manometer (31) connects the outlet of the test chamber (12) with the pipe tee (10).

The first outlet of the valve (5) is connected to a hose (13) linking it with the inlet of the hot fluid tank (14). The second outlet of the valve (5) is connected to a hose (15) which ended with pipe tee (16). The first outlet of the pipe tee (16) is connected through a hose (17) with the cooler (18), whose outlet is connected

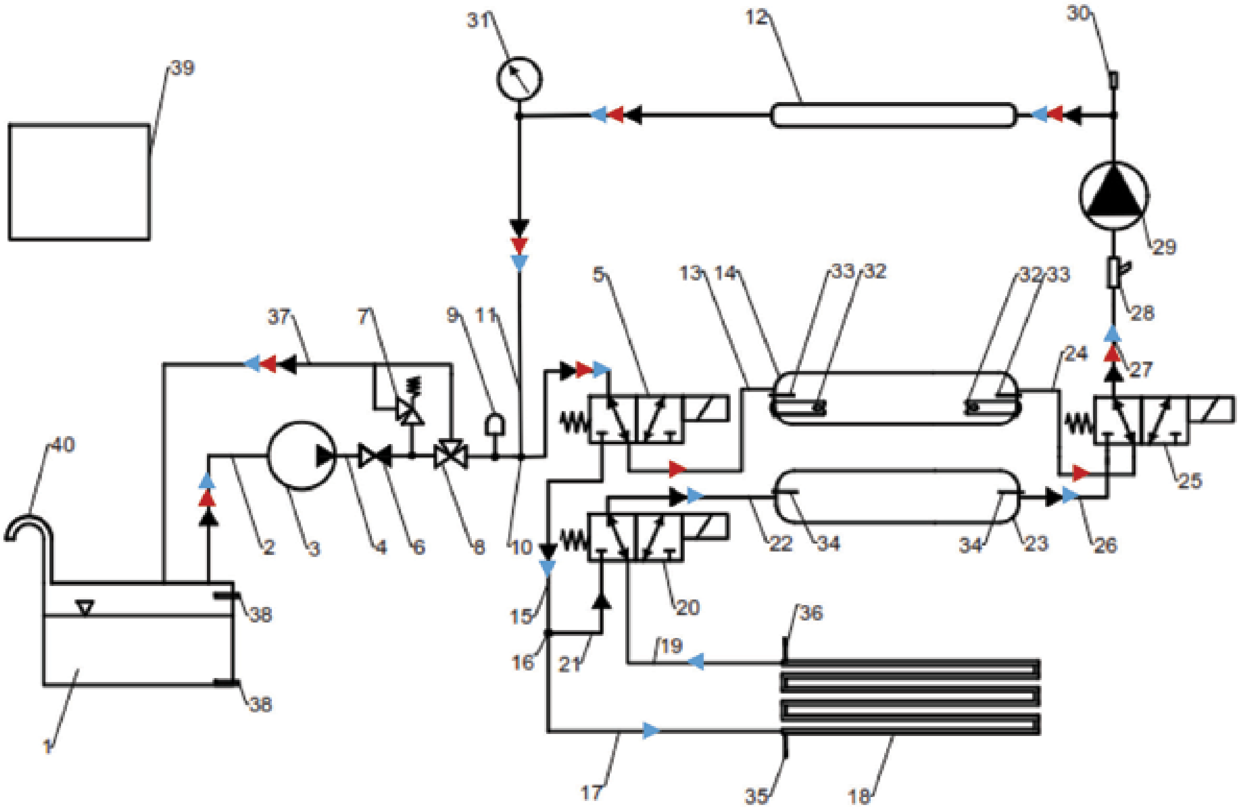

Fig. 2. Schematic description of the stand with marked circulation of liquids: warm cycle – red arrows; cold cycle with circulation through the cooler – blue arrows; and cold cycle – black arrows

through a hose (19) with the first inlet of the three-way two position valve (20). The second output from the pipe tee is connected to the second inlet of a valve (20) by a hose (21). The outlet of the valve (20) is connected by a hose (22) with the inlet of the cold fluid tank (23).

Outlets of the cold fluid tank (23) and the hot fluid tank (14) are connected to a three-way two position valve (25) by hoses (26) and (24). The outlet of the valve (25) is connected to the inlet to the test chamber (12) by a hose (27). On the hose (27), there are a residue filter (28), a circulating pump (29), and a venting device (30).

The cold fluid tank (23) and the hot fluid tank (14) are equipped with fluid temperature sensors (33, 34). Moreover, on the inlet and outlet of the hot fluid tank (14), there is an electric resistance heater (32). Fluid temperature sensors (35) and (36) are also on the inlet and outlet of the cooler (18).

The inlet of release valve (8) and the inlet of safety valve (7) are connected to the tank (1) by a discharge line (37). Fluid level sensors (38) and the vent (40) are mounted in container (1).

Fluid temperature sensors (33, 34, 35, 36), fluid level sensors (38), the manometer (31), the release valve (8), the pressure switch (9), heaters (32), the pressure pump (3), the circulating pump (29), and three-way two position valves (5, 20, 25) are connected with the controller (39).

In the test chamber (12), specimens (unmarked in the figure) are mounted. One form of the test chamber can be a specimen of a pipe or a system of pipes connected in series or parallel. In the second case, each specimen has independent valves to enable their switching on and off from the medium circulation (hydraulic fluid). Configuration of the test chamber in the series and parallel system is shown in Figure 3.

To test specimens, they are mounted in a test chamber (12). After the controller (39) is switched on, a pressure pump (3) fills the hydraulic system with fluid from the tank (1). In the tank (1), the pressure is equalized through a vent (40). The circulating pump (29) turns on. The air is removed from the system through the vent (30). The valves (5), (20), and (25) periodically change the flow direction, which causes the filling of the hot fluid tank (14), the cold fluid tank (23), the cooler (18), and the rest of the system. Once the pressure assigned in the controller (39) is reached, a pressure switch (9) turns off the pressure pump (3). Further, the pressure pump (3) is activated by a pressure switch (9), only when a pressure drop by a given value is reported, and it works until the required pressure is reached.

Fluid in tank (14) is warmed up by electric resistance heaters (32). Controller (39) turns on and off heaters (32) on the basis of information from fluid temperature sensors (33) maintaining the assigned temperature.

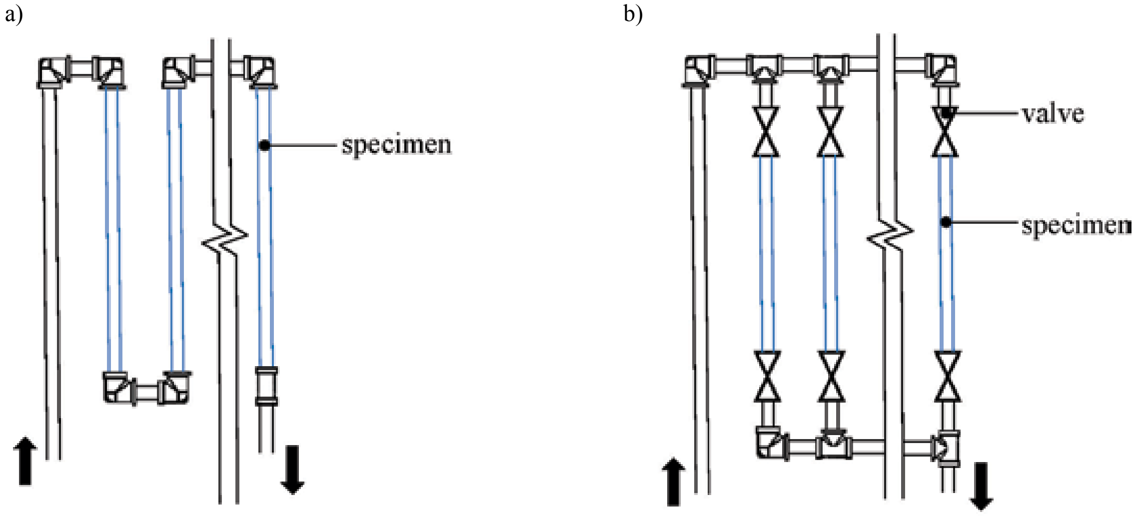

Fig. 3. Serial (a) and parallel (b) arrangement of pipes in research chamber

The hot cycle is started via the controller (39), which opens the inflow of fluid on valve (25) through hose (24) from hot fluid tank (14) and the outflow of fluid through the hose (13) to the hot fluid tank (14) on the valve (5). Circulation of fluid through the cold fluid tank (23) and cooler (18) is completely cut off. Fluid is pumped by the circulating pump (29) from hot the fluid tank (14) through the test chamber (12), and then it comes back to the hot fluid tank (14), under increased pressure produced by the pressure pump (3), which operates only when pressure fall occurs, down to the value assumed for testing. A pressure increase above the value assumed for tests causes the opening of inflow in the safety valve (7) and through the discharge line (37) to remove excess of the fluid to tank (1).

After the time assigned by the controller (39), the cycle changes into the ‘cold’ phase (blue colour). At the beginning of the ‘cold’ cycle, the controller opens the following:

- The inflow of fluid through the hose (26) from the cold fluid tank (23) on the valve (25),
- The outflow of fluid to the hose finished with a pipe tee (16) on the valve (5), and
- The inflow of fluid through the hose (19) from the cooler (18) on the valve (20).

Fluid is transported by the circulating pump (29) from the cold water tank (23) through the test chamber (12). Warm fluid that remained in the pipes (11) and (27) and the test chamber (12) after the hot cycle is removed from the circulation by cold fluid to the cooler (18). Water remaining in the cooler (18) is moved to the cold fluid tank (23). The capacity of the radiator is slightly higher than the capacity of the pipes and test chamber (12). The temperature sensor (36) on the cooler outlet provides controller (39) with information about the fluid temperature increase, which means filling the radiator with warm fluid. The controller opens a valve (20) to the inflow of fluid from the hose (21), which cuts off the fluid flow through the cooler (black colour). It enables the fluid to cool in the radiator during the cold and the hot cycle before it is pumped to the cold fluid tank (23) once another cold cycle is started. For the rest of the cold cycle, the cold fluid circulates between the cold fluid tank (23) and the test chamber (12). During the entire cold cycle, the circulation of the fluid through hot fluid tank (14) is cut off. After the time specified in the controller (39), the cycle changes into the hot phase. Valves (5) and (25) change position as described by the hot cycle. Cold water that remained in hoses (11) and (27) and the test chamber (12) goes to the hot fluid tank where it is mixed with warm fluid. The volume of warm fluid in the tank (14) is the amount needed to not allow the fluid temperature in the tank to drop below the level specified by the standard for the hot cycle after its being mixed with cold fluid, following the change of the cold cycle into the hot one (14).

The controller (39) records the results of temperature measurements from fluid temperature sensors (33), (34), (35), and (36), the manometer (31), and counts the time and the number of cycles. In the case of a significant drop in the fluid height in the tank (1) caused by, e.g., the depressurization of the hydraulic system or the destruction of the specimen and loss of fluid from the system, the controller (39) turns off pressure pump (3), circulation pump (29) and heater (32), opens bottom valve (8), and drains the remaining fluid to tank (1). It is also possible to stop pressure pumps (3), the circulation pump (29), and heaters (32) by means of the panel of the controller (39) by the operating crew.

A change of pressure or cyclic pressure is possible while testing. In such a case, the reduction of the pressure value in the system is possible through the opening of the drainage valve (8) through the controller (39) and it is closing once the assumed value of lower pressure is reached.

The pressure is increased to the target value by switching on the pressure pump (3) by means of the pressure switch (9).

3. Stand verification

The proposed solution was applied in a research station (Fig. 4) and verified during multilayer pipe (PE-X) testing. Temperature and pressure was measured for a single thermal cycle. The fluid temperature change occurs in a time shorter than 60 seconds, which meets the requirements of the standard PN-EN ISO 15875-5.

The temperature of hot and cold liquid varies within ±0.5°C. The cold liquid is more susceptible to changes in temperature due to the need to cool it in the cooler. The volume of cooled liquid corresponds to the volume in the measuring part when the cycle changes from hot to cold. This liquid remains in the radiator for 30 minutes until the next cold cycle. At this time, it must lower its temperature, so that it does not rise above the permissible value while mixing with the liquid from the cold reservoir. Depending on the ambient temperature, the cold liquid in the tank stabilizes its temperature at a different value. During the tests, the ambient temperature was, on average, 18°C. The temperature of the water in the tank after several cycles stabilized at about 24°C. It is possible to use fans that accelerate the heat transfer to the environment.

Pressure is maintained at the level of 10±0.2 Bars. Due to slight leaks, the pressure in the system slowly drops. The pressure pump is activated, on average, once per cycle and worked for a few seconds. The above presented measurement results allow us to say that the test stand provides the possibility to apply thermal and pressure loading specified in the standard PN-EN ISO 15875-5.

The developed stand allows for conducting advanced investigations during the implementation of tests, such as stress measurements in the pipe or analysis of the temperature using thermography.

As an example, results of longitudinal stress analysis in external layer of PE-X pipe is shown in Figure 5. For stress analysis, the strain gauge technique was applied.

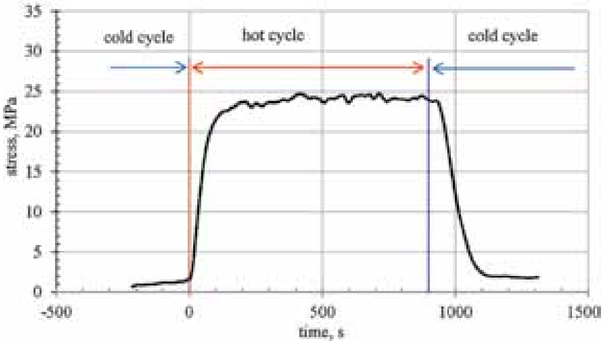

Fig. 5. Example of stress analysis in the multilayer pipe with the use of a strain gauge

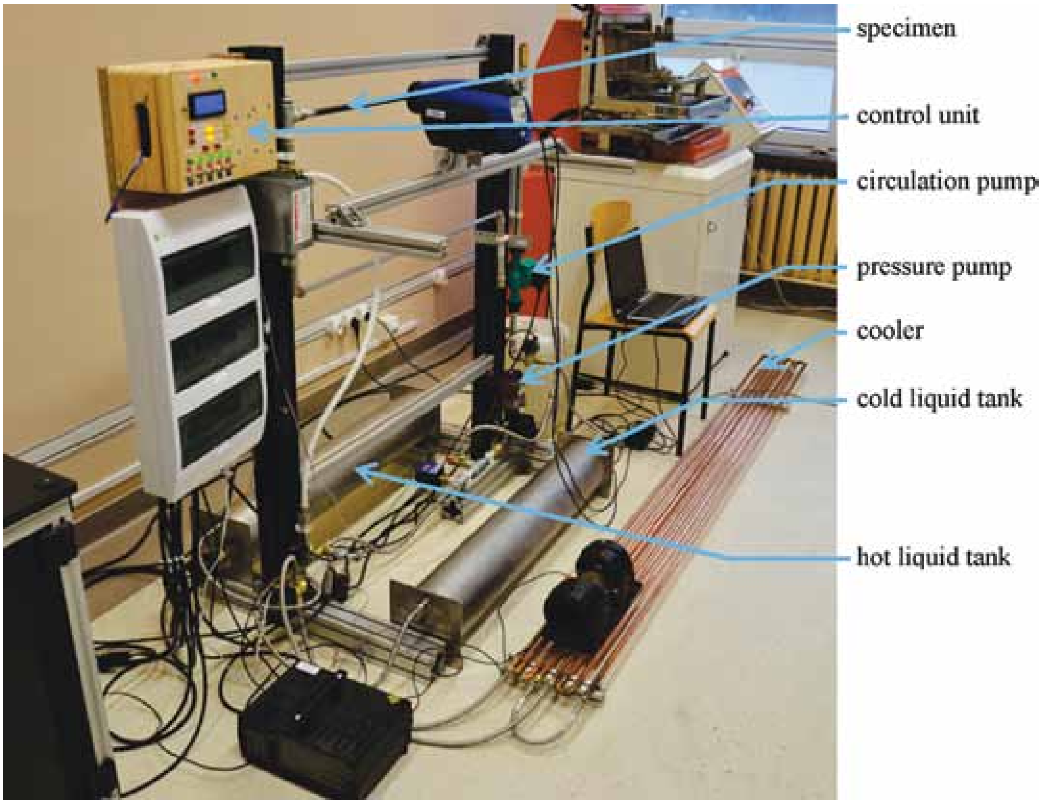

Fig. 4. Stand for thermocycling of pipes and their joints

In turn, an example of local temperature distribution analysis with the use of thermography is presented in Figure 6.

Summary

The system discussed in the study allows the control of the temperature of flowing fluid as well as the pressure. The simple and compact structure of the test stand makes it possible to reduce the space needed to construct the test stand. The closed circuit of the fluid enables the reduction of its volume. The operation of the system under high pressure with a temporarily mounted pressure pump to equalize pressure to a given value assumed for tests contributes to the energy efficiency and almost complete minimization of noise generated by the pumps. Construction of the system from elements available on the market does not require high expenditures. Full automation of the test stand enables practical and safe hands-off operation. The lack of tightness of the system or the destruction of the specimens causes an automatic, maintenance-free stop of the test. This prevents fluid leaking from the system and damage to the pumps. An important feature of the stand is the ability to adapt it to the use of many different pipe specimens and their connections with full access to them during the tests. This enables the use of many additional measurement methods, including thermovision, tensometric measurements, and optoelectronic measurement technologies.

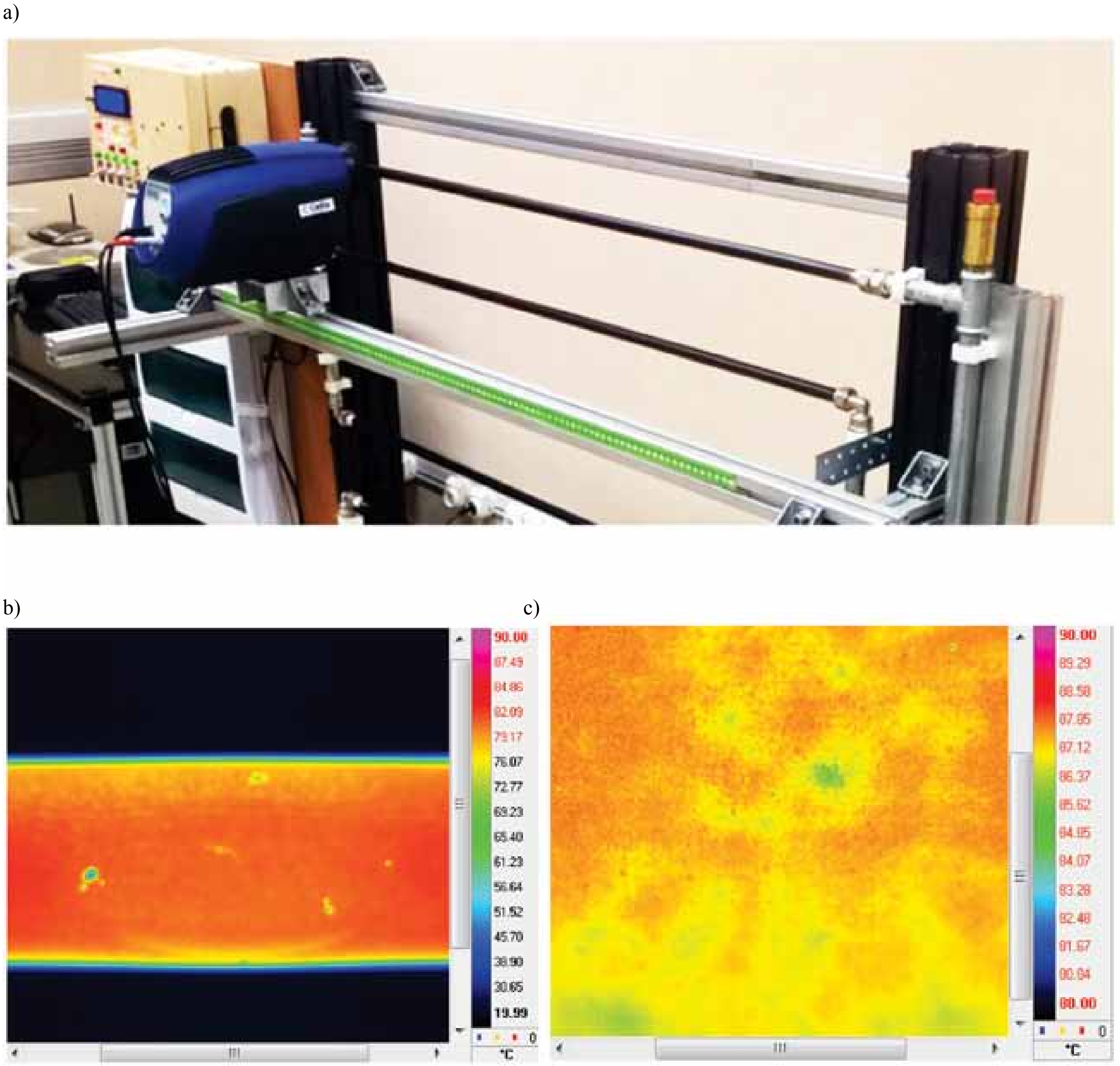

Fig. 6. **Example of temperature distribution using thermography: a) thermographic camera installed on the stand, b) global temperature distribution, c) local temperature distribution**

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