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New materials intended for use within natural gas installations and quality testing procedures

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Abstract. Traditionally, in Romania, steel pipes and fittings are used within the natural gas supply installations. However, in many European Union countries, other types of materials are also used: copper made pipes and fittings, respectively multiple-layers pipes of PEXAL type. The present paper describes the results of the research work performed by the authors aiming at aligning the Romanian standards to the European ones, in order to make possible the use of these materials within the natural gas installations in Romania, besides steel and polyethylene. Such work had as main result the development and certification of a set of testing procedures (described in this paper) required for the quality assessment of the assembly technologies (with press fit or hard soldered joints) of copper pipes and fittings, including the design and construction of the equipment needed in order to perform these tests (presented in a separate paper [1]).

Keywords: natural gas installations; pipes; fittings; copper pipes; pipes of PEXAL type; press fit.

1. Introduction

Traditionally, both in Romania and in the other countries from South-Eastern Europe, steel pipes and fittings are exclusively used within the natural gas installations (internal and external), while for buried pipelines either steel pipes, externally insulated, or high density polyethylene pipes (PEHD) are used. These are the materials officially regulated by the Norms approved in our country by the National Energy Regulatory Authority (ANRE).

However, in most of the European Union countries (Germany, France, Belgium, Netherlands, Italy), and not only, other types of materials, besides steels, are also

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allowed for use within the natural gas installations. The concerned new materials are copper or copper alloys (bronzes) pipes and fittings, and multiple-layers tubes made of polyethylene and aluminum of the type PE-XC/Al/PE-X or PE-X/Al/PE-X (known under the abbreviation PEXAL type pipes).

The advantages that both copper and PEXAL type pipes have towards the steel pipes are: higher corrosion resistance; smaller pipe wall thickness required; better behaviour at both low and high operating temperatures; simpler assembly technologies.

With the scope of accelerating the introduction of these new materials in the Romanian Norms for the design and execution of the natural gas installations, and therefore allowing for their use in practice, researches have been carried out by the authors in order to attest their behaviour during operation [2, 3]. The starting point of our research have been the European norms addressing the use of copper pipes for gas installations [4-16].

The authors have investigated in detail both the materials and the assembly technologies used world-wide for copper and PEXAL type pipes, and they have developed the procedures required for the quality assessment of these technologies. The most promising, newest assembly technology was found to be the press fit technology, using a special sealing element.

Such technology can be used for the assembly of copper pipes (with a nominal diameter between 12 and 108 mm) within gas installations at operating temperatures ranging between -20 °C and +70 °C, and a MAOP (maximum allowable operational pressure) not greater than 5 bar. Another technology that can be successfully used in the same conditions, but with less promising results, is hard soldering.

The testing procedures for the assembly technologies of copper pipes and fittings have been developed aiming at the fulfilment and proper certification of all technical requirements which guarantee the safe exploitation (both in normal operating condition and in accidental ones – generated by earthquakes, fires etc.) of the natural gas installations. The main scope of these procedures is to validate the tightness of full-scale specimens (made of copper pipes and fittings using a given assembly technology) subjected to both static and dynamic loads, and also to extreme (high/low) temperature conditions. The testing conditions for the quality assessment of the assembly technologies have been defined based on the working characteristics of the gas installations made of copper pipes.

2. Materials, equipment and assembly technologies used for pipes of PEXAL type

The pipes of PEXAL type are made of three coaxial tubes arranged as follows: a polyethylene tube at the inside, an aluminum tube obtained from a sheet band rolled and longitudinally welded (using TIG welding procedure) at the middle, another polyethylene tube at the outside, made by extrusion. No overlays of the aluminum band, without welding, are allowed.

An adhesive is introduced between these three tubes and therefore the PEXAL pipe practically has in its cross-section five layers, cohesive between them, which confer a very good mechanical strength and especially an outstanding strength under internal pressure (up to about 90-100 bar) loadings.

The nominal diameter values and the nominal thickness values (for the pipe wall thickness and for the aluminum layer) allowed for the pipes made of PE-Xc/Al/PE-X or PE-X/Al/PE-X are given in Table 1 [17, 18].

Table 1. Outside diameter, minimum wall thickness and min. thickness of al layer for pipes of pexal type

Outside Diameter, [mm]	Minimum wall thickness, [mm]				
	2.0	2.5	3.0	3.0	3.5
16	0.4	-	-	-	-
20	-	0.5	-	-	-
26	-	-	0.6	-	-
32	-	-	-	0.8	-
40	-	-	-	-	1.0

The main categories of fittings and pipes of PEXAL type are pictured in Fig. 1.

The fittings are of the following types:

- with crimped joints, simple (crimped only) or mixed (crimped and screwed), provided with a body made of bronze or polyamide, two sealing gaskets of O-ring type (EPDM) and a stainless steel cylinder for external crimping;
- with compressed joints (REHAU type), simple (only compressed) or mixed (compressed and screwed), provided with a body made of bronze or brass, two sealing gaskets of O-ring type (EPDM) and a bronze / brass cylinder for external compression.



Fig. 1. Fittings and pipes of PEXAL type.

The equipment listed below is compulsory in order to build the gas installation made of PEXAL pipes and to assemble the pipes and fittings of this type:

- cutting devices for the tubes of the type PE-Xc/Al/PE-X or PE-X/Al/PE-X (roller cutter);
- tools for trimming off the ends of the cut pipes (both at the outside and at the inside);
- crimping (cold pressing) device (of the type manual, pneumatic or electro-hydraulic); such device shall be provided with a mechanism that does not allow for its opening before the crimped assembly is correctly executed;
- compression device (of the type manual, pneumatic or electro-hydraulic), also provided with a mechanism not allowing for its opening before the compression is correctly executed.

The provision of detection, warning and protection systems for fuel natural gases, carbon monoxide and smoke is compulsory, in case pipes made of PE-Xc/Al/PE-X or PE-X/Al/PE-X and crimped or compressed fittings are used. This is due to the fact that, in case of fire, whatever its origin, the O-ring type rubber gaskets will burn out and gas leakage can occur.

The following requirements shall be fulfilled when executing gas installation by using PEXAL type pipes:

- the temperatures at which the pipes of the type PE-Xc/Al/PE-X or PE-X/Al/PE-X are operated and assembled shall be at least equal to +50C and not greater than +400C;
- cold bending of the pipes made of PE-Xc/Al/PE-X or PE-X/Al/PE-X can be performed, with or without special devices, only at prescribed values of the curvature radius;
- 90 degrees direction changes, ramifications and reductions are to be made only with factory fittings with the exception of cold bends that shall be performed only at the recommended minimum curvature radii;
- the PEXAL pipes and fittings will be assembled by means of crimping or compressing the fittings upon the pipes by using the specific device for each assembly procedure.

3. Materials used for copper pipes and fittings

Currently, a worldwide trend to generalize the use of copper as a material for the construction of natural gas and liquefied gas supply systems, plumbing installations, fire extinguishing installations, etc. is noticeable. Such situation is due to the much more “friendly” behaviour of the copper pipes when compared with steel pipes.

The use of copper pipes within the natural gas installations has been authorised in the European Union, based on a severe system of authorization procedures (described in the Norms: EN 1254-1 [7], EN 1057 [8], EN 1982 [10]).

The copper grades normally used are Cu - DHP or CW999A (having at least 99.90

% Cu + Ag, and limited phosphorus content, $0.015 \% \leq P \leq 0.040 \%$). The mechanical properties of the copper pipes are included in Table 2.

Table 2. Copper pipes. mechanical properties

Class Symbol	CEN 133/99	R 220	R 250	R 290
	Characterization	soft	half-hard	hard
Outside diameter, mm	min.	6	6	6
	max.	54	66.7 / 159	267
Tensile strength	Rm, MPa min.	220	250	290
Elongation at break	A, % min.	40	30 / 20	3
Hardness (optional)	HV5	40-70	75-100	min. 100

The standard values defined for the outside diameter of the copper pipes used within the natural gas installations are included in the range 6 ... 267 mm, while their nominal wall thickness values may vary from 0.5 up to 3.0 mm.

The fittings for the assembly of copper pipes are manufactured from copper or copper alloys. These materials are regulated by the European Union norms [10, 11] and by CEN/TC 133 [16]. The materials normally used to manufacture these fittings are presented in Table 3.

Table 3. Materials normally used to manufacture copper fittings

Material		European Norm
Symbol	Number	
Cu – DHP	CW024A	EN 12449
CuSn5Zn5Pb5-C	CC491K	EN 1982
CuZn36Pb2As	CW602N	EN 12164
CuZn39Pb3	CW614N	EN 12164
CuZn33Pb2-C	CC750S	EN 1982
CuZn15As-C	CC760S	EN 1982

As detailed in [2], due to the fact that the copper pipes wall thickness values are smaller than the ones of steel pipes and the roughness of the inner surface of the pipes is very smooth, the design norms differ with respect to the ones referring to steel pipes and fittings. This statement is also valid for the pipes and fittings of the PEXAL pipes.

4. Equipment and assembly technologies used for copper pipes and fittings

The main technologies presently in use for the assembly of the fittings to the copper pipes are: soft soldering; brazing (hard soldering); tightening, with the development of the radial pressure using bolts assemblies; cold pressing (press fit jointing / crimping), for which the assembly / tightening between the pipe and the fitting is achieved by means of the radial plastic deformation of the fitting.

The strength and technical safety requirements of the natural gas installations have led to the authorization, in the European Union, of two assembly procedures, hard

soldering and cold pressing (the authorization procedure is given by EN 1254 [6, 7]), among which the second procedure has been proven more advantageous. The press fit assembly system presupposes the existence of some special fittings provided during manufacturing with recesses for the elastic gaskets, also named pressing fittings (see Fig. 2). A basic condition for successfully achieving a quality joint by means of this procedure is that the wall thicknesses of the fittings are uniform and, in addition, the fittings do not have deviations from the cylindrical shape, in order for the tightening to be uniform on the entire circumference.

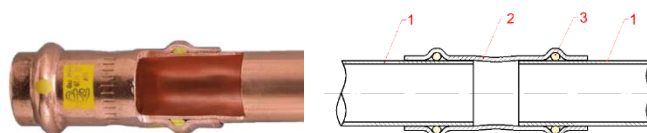


Fig. 2. Cold pressing assembly:
1 – copper pipe; 2 – press connector fitting; 3 – sealing ring

The main advantages of the permanent assembly system by cold pressing in comparison with the traditional assembly technologies (brazing or welding) are:

- the duration of the press fit assembly operation (of about only 4 seconds) represents approximately 30% from the duration of the assembly by soldering/welding;
- the preparation and cleaning operations of the pipes after soldering/welding are eliminated;
- the material needed for soldering/welding – soldering alloys, electrodes, oxygen, fuel gases etc. – are not needed;
- the risk of the corrosion of the copper pipes due to the transformation products of the pickling paste and to thermal effects is reduced;
- fire prevention measures for the soldering/welding works in dangerous places for working with flame (wooden houses, silos, renovations etc.) are not necessary;
- the mechanical stresses from the natural gas supply system are eliminated, as cold pressing can be performed after setting in position the entire gas installation, with the correction of the deformations due to the walls geometry, of the small errors during pipes cutting, etc.;
- the productivity of the execution of natural gas installation is higher when using press fit assembly technology;
- the natural gas installations made of copper pipes are guaranteed for a period of at least 50 years.

As a result of the research work of the authors, a permanent assembly system with connections / fittings made of copper (Cu 99.9 %) or bronze (0.4-0.8 % Ni, 3-3.5% Pb, 6.5-7.5% Zn, 3.8-4.5% Sn, the rest Cu), by cold pressing, using an elastic sealing gasket (acrylonitrile-butadiene rubber) and an electro-hydraulic pressing system, has been developed.

Fittings are provided, during the manufacturing process, with a pore on the inner

surface of the channel in which the sealing ring is placed. This pore closes itself during the cold pressing assembly operation. As a consequence, if a press fit joint has not been assembled, during the pressure test performed for commissioning the natural gas installation, a pressure loss will be recorded. In such case, all fittings will be visually controlled and the unassembled joint will be identified.

The press fit jointing technology of the fittings with the copper pipes within the natural gas installations, named Profipress G [3], presupposes the existence of an equipment consisting of a device used for cutting the copper pipes, a tool for trimming off the ends of the cut pipes, and an electro-hydraulic device for the cold pressing itself (see Figure 3). The electro-hydraulic device can be used for several types and dimensions of fittings / pipes, as it is provided with several pairs of wedge grips, corresponding to each standard dimension.



Fig. 3. Electro-hydraulic press fit device

The average duration of achieving of the press fitting itself is of about 4-5 seconds. When constructing the gas installations, the following recommendations should be taken into account:

- the temperature of the operating environment shall be within the range +5 ... +40° C;
- cold bending of copper pipes can be performed, with or without special devices, if complying with the minimum curvature radii recommended;
- the direction change of 90 degrees, the ramifications and reductions are to be made only with factory fittings;
- the copper pipes can also be installed in slots (ditches) covered (masked) with grids;
- the pipes can be supported by bracelets or consoles, placed at standard distances as a function of the pipes diameter;
- the provision of detection, warning and protection systems for fuel natural gases, carbon monoxide and smoke is compulsory, because, in case of fire, the O-ring type rubber gaskets will burn out and gas leakage can occur.

5. Quality testing procedures for the permanent assembly technologies used for copper pipes and fittings

The elaboration within our university of the technical norm regarding the design, execution technology and exploitation of the natural gas installations, made of copper or PEXAL type pipes, has been based on a set of procedures for the technical certification of the assembly technologies and for the experimental verification of the strength and tightness of these assemblies under all types of loadings – mechanical, thermal, fatigue. Within the European Union, based on such a set of procedures, technical norms for the permanent joints obtained by cold pressing the metallic pipes have been developed (DVGW VP 614 [4] and DVGW 534 [5] in Germany).

Based on the Norms VP 614 [4] and EN 1254-7 [6], the following testing procedures for the quality assessment of the permanent assemblies of the copper pipes and fittings have been developed by the authors [2, 3]:

1. The procedure for the strength and tightness testing under internal hydrostatic pressure, shown in Figure 4. A full-scale specimen, 6, made of one or more fittings, 5, assembled to a copper pipe, 4, with the minimum required length specified in Fig. 4, is submitted to a hydrostatic water pressure of 30 ± 1 bar, with a specified duration of 48 hours. The equipment used consists of a manual water pump, 2, connected to a pressure stabilizer and a precise water pressure measurement device, 1. The technical requirement of this test is that, both during and after the test, all the specimens shall keep their tightness (no fluid leakage must be recorded).

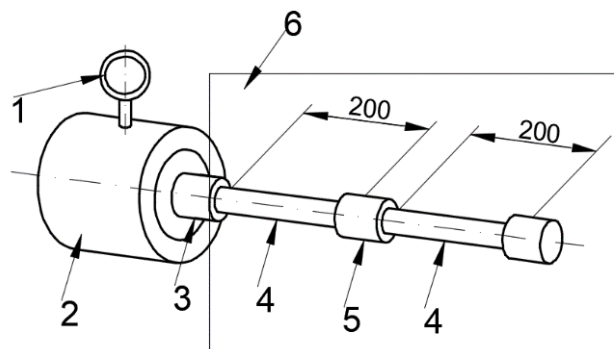


Fig. 4. Device for the internal (hydrostatic or pneumatic) pressure testing of the copper pipes assemblies:

- 1 – manometer, 2 – pressure generating device, 3 – sealing element,
4 – copper pipe, 5 – fitting, 6 – specimen

2. The procedure for the strength and tightness testing under internal pneumatic pressure, also illustrated by Fig. 4. The specimen 6 is submitted to three successive air pressure tests, each one with a duration of 10 minutes and a specified pressure value ($1.1 \times$ nominal pressure, 110 mbar and 22 mbar respectively). The technical requirement of such test is that, during its three

phases, the specimens shall keep their tightness (no air leakage must be detected). The equipment used for this test consists of an air compressor, 2, a connection system, 3, to the specimen, 6, and a precise air pressure measurement device, 1.

3. The procedure for testing the temperature influence upon the tightness of the assemblies aims at determining their tightness for various values of their operating temperature. A specimen, made of copper pipe and one or more fittings, is subjected to a specified maximum temperature of 70 ± 2 °C, during one hour, and to a specified minimum temperature of -20 ± 5 °C, with a duration of 24 hours. The technical requirement of the test is that, after performing it, all the specimens shall keep their tightness. The used equipment consists of a heating device (electrical furnace), a cooling device (freezer), and a temperature measurement device.
4. The procedure for the dynamic strength and tightness testing of the assemblies under symmetrically alternating torsion loads. A full-scale specimen, made of one fitting and two copper pipes, having a rigidly fixed end, is subjected to an alternating torsion load with a constant specified amplitude of ± 50 , for a specified number of 10 load cycles, each cycle having a specified duration of one second, at atmospheric pressure. The technical requirement of this test is that the tested specimens shall keep their mechanical strength and tightness after loading. A special equipment, described in a separate paper [1], has been designed and built by the authors to apply this procedure.
5. The procedure for the mechanical strength and tightness testing under static bending loads. A specimen, made of two copper pipes, 2, and one fitting, 3 (see Fig. 5), is submitted, under a specified internal air pressure of 5.5 ± 0.5 bar, to a static bending load which is a function of its nominal diameter, for a specified duration of one hour. The technical requirement of such test is that, both under loading and after performing the test, the specimen shall keep both its mechanical resistance and tightness (no air leakage must be observed). The required equipment (pictured in Fig. 6; see also the scheme in Fig. 5) consists of two supports which sustain the ends of the specimen, the device which applies the test load by means of calibrated weights, 4, in the middle of the specimen, and an air pressure generating device (an air compressor), connected to the specimen using a special joint, 5.

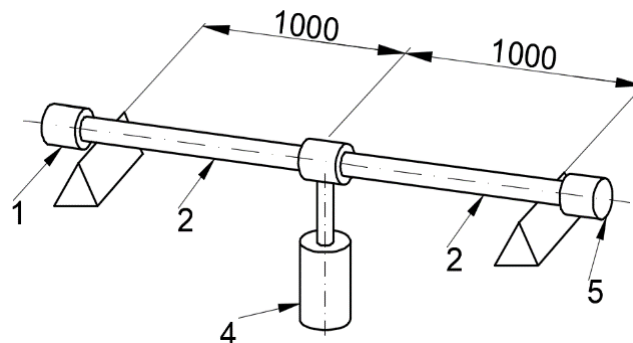


Fig. 5. Scheme of the device for the static bending testing of copper pipes assemblies:
1 – cap, 2 – copper pipe, 3 – fitting, 4 – weight, 5 – pressure connection

6. The procedure for testing the assemblies` dynamic strength under symmetrically alternating bending loads (vibrations). An U-shaped full-scale specimen, made of four fittings and several copper pipes, with a fixed end, is subjected to vibrations by means of an alternating deformation with a constant specified amplitude of ± 1 mm and a specified frequency of 20 Hz, during a specified duration of 106 loading cycles, at atmospheric pressure. The technical requirement of the vibration test is that the specimen shall keep its mechanical strength and tightness after loading. A special equipment, described in a separate paper [1], has been conceived and constructed to apply this procedure.



Fig. 6. Picture of the device for the static bending testing of the copper pipes assemblies

7. The procedure for testing the operating capacity at high temperature. A full-scale specimen, heated at a specified temperature of 650 ± 10 °C, is subjected, for a specified duration of 30 minutes, to a nitrogen internal pressure of 5 ± 0.5 bar and it shall not experience gas lost (at any of its ends), as a result of leakage, with a flow rate greater than $30 \text{ dm}^3/\text{h}$. The specimens for which the gas leakage is within the specified limit are considered to fulfil the quality requirements regarding the exploitation at high temperatures. Also for this procedure, a special equipment, described in a separate paper [1], has been conceived by the authors.

The testing temperature should be 23 ± 5 °C (room temperature) for all the testing procedures presented above, if not specified otherwise.

In order to test the strength of the press fit joints, which have studied within the research work presented in this paper, hydrostatic pressure tests have been also performed. The used fluid has been water at room temperature.

During all the tests performed, it has been observed that failure (cracking) occurred in the copper pipes while the press fit joints have not been affected. In Fig. 7, one of the tested joints, made of copper pipe having a diameter of 15 mm and a wall thickness of 1 mm, has been pictured after its failure at the pressure of 230 bar.

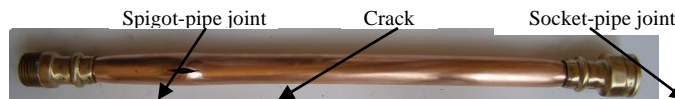


Fig. 7. Picture of a specimen tested at hydrostatic pressure

6. Conclusions

We consider that the alternative, analysed in the present paper, of using copper and PEXAL type pipes for the construction of the natural gas installations will impose itself – alongside the alternative of using steel pipes – in the near future also in Romania.

The advantages that both copper and PEXAL type pipes have towards steel pipes are: higher corrosion resistance; lesser wall thickness; better behaviour at low and high operating temperatures; simpler assembly technologies.

This paper also presents a modern procedure for press fit jointing, using a special metallic or non-metallic sealing element, of copper pipes and fittings for the natural gas installations. This procedure is an alternative for the hard soldering (with silver-based alloys) and welding procedures.

Moreover, the present paper describes a set of testing procedures developed by the authors for the quality assessment in accordance with the European norms of the permanent assembly technologies of the joints of copper pipes and fittings used within natural gas installations. The equipment conceived and built within the Petroleum-Gas University of Ploiesti for three of these procedures (the dynamic strength test under bending loads/vibrations, the strength test under dynamic torsion loads and the operating capacity at high temperatures) is presented in a separate paper [1].

In order to validate the testing methodologies and procedures conceived, full-scale specimens of copper pipe joints of various types and dimensions have been designed and constructed using the press fit technology. These specimens have been successfully subjected to tests performed (according to the seven procedures defined) within a complex testing program.

The usage manual for the proposed assembly technologies has also been elaborated by the authors and a pilot natural gas installation made of copper pipes and fittings has been successfully designed, built and monitored for several years (during which no leakage has been recorded) in order to validate all the procedures.

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