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In-service Repair of the Transmission Pipelines

Gheorghe Zecheru*, Gheorghe Drăghici*, Ilie E. Laţa**, Alin Diniţă*

* Universitatea Petrol – Gaze din Ploieşti, Bd. Bucureşti, 39, Ploieşti
e-mail: gzecheru@upg-ploiesti.ro

** S.N.T.G.N. „TRANSGAZ" S.A., Pta. Constantin I. Motaş, 1, Mediaş
e-mail: ilie.lata@transgaz.ro

Abstract

In this work the repair technologies of the fuel fluid transmission pipelines (oil, liquid petroleum products and natural gas), with and without welding operations, are analyzed comparatively. There has been highlighted the advantages and disadvantages of the repair technologies based on the welding application of additional elements (patches or full encirclement steel sleeves) and those based on composite reinforcement sleeves. It has been also presented the criteria used for selecting the repair technologies (with and without welding) when the in-service repair is carried out.

Key words: *transmission pipeline, in-service repair, repair by welding, composite sleeves repair*

Usual Repair Procedures for Pipelines

The defects in the steel pipes of transmission pipelines, the so called flaws having important negative influences upon the correct operation and the carrying capacity of the pipeline, which require measures of supervision and maintenance, can be classified in three categories: a) geometrical defects, created by local deformations of the pipes, in this category we can mention the modification in size and shape, which significantly modifies the cross section of the pipeline, the main types of such defects are the grooves and the local deformations or the dents; b) metal loss defects, which consist of the general or local thinning of the pipe wall by the loss of metallic material, due to corrosion and / or erosion; c) crack-like flaws, which can be generated during the operation of the pipeline because of fatigue, stress corrosion cracking, hydrogen induced cracking, etc, or defects that might exist on the pipes before putting the pipeline into operation (cracks produced during milling or cracks in the welded joints of pipes) [1].

The usual technological procedures used for repairing the steel pipe defects have been classified and codified by the authors of this work as shown in figure 1; for instance, the technology codified *0011 – 04* corresponds to the reconditioning of a pipeline without taking it out of service, by applying a B-type sleeve. As transporting crude oil, liquid petroleum products and natural gas are considered very important tasks, which have to be continuously provided, the usually selected and used technological repair procedures are those that can be applied without taking the pipelines out of service. Consequently, in this work these repair procedures are analyzed comparatively, there are highlighted the technological specific features of using these procedures and there are also presented criteria for assessing the quality of the performed repair works.

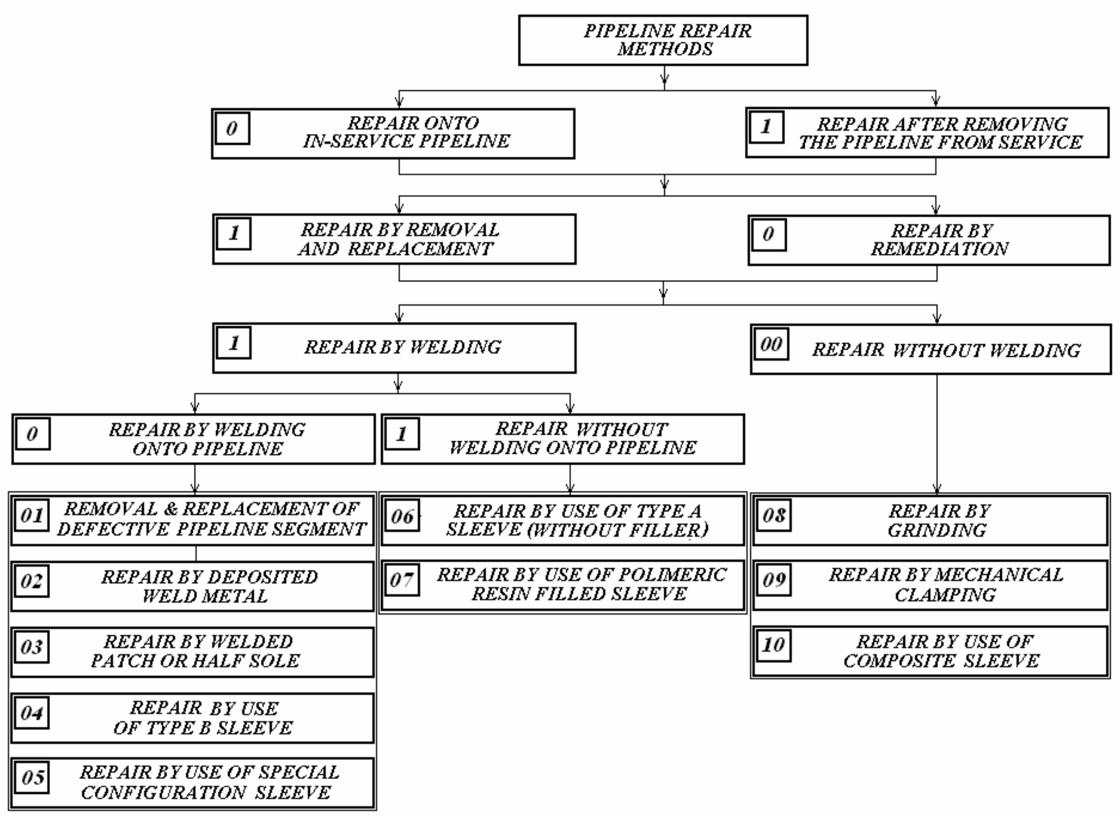

Fig. 1. Classification and codification of the technological repair procedures of the transmission pipelines

Specific Features of Welding Pipelines

As it can be seen in figures 2 and 3, applying the technological procedures of maintenance for transmission pipelines may imply the carrying out of two types of welded joints: a) longitudinal welded joints – ISL, carried out between semi-cylindrical components elements like A and B – type sleeves are made of or wraps filled with synthetical resin; the performance of ISL does not thermically and metallurgically significantly influence the pipe wall, and the type of joint (butt or fillet weld) depends on the solution chosen while designing the weld jointed components; b) circular welded joints or outline welded joints – ISC, carried out for fixing (applying) B – type sleeves or remote mounted wraps and patches, as well as for assembling the replaced pipe sections; ISC are butt or fillet welded joints and their performance affects directly and considerably, thermically, metalurgically and mechanically the pipe wall by generating a field of residual stresses.

Under these circumstances it can be estimated that, no matter which the condition of carrying out the maintenance works are – with or without taking the pipeline out of service – the procedures for ISL must be conceived according to the customary methodology used for welded joints when designing the pipelines and doesn' t require any special analyses [2,3].

In the same context it results that, no matter which the conditions of carrying out the maintenance works are – with or without taking the pipeline out of service – the ISC must be carefully analyzed for highlighting the features of the welding procedures for these joints; the comparative analysis of the physical models corresponding to the performance of ISC on out-of-service (non-pressurized) pipes and on in-service pipes (through which there are spread, with certain flow rates, fluids under pressure) must be the foundation of formulating the technological indications of the procedures for carrying out these welded joints.

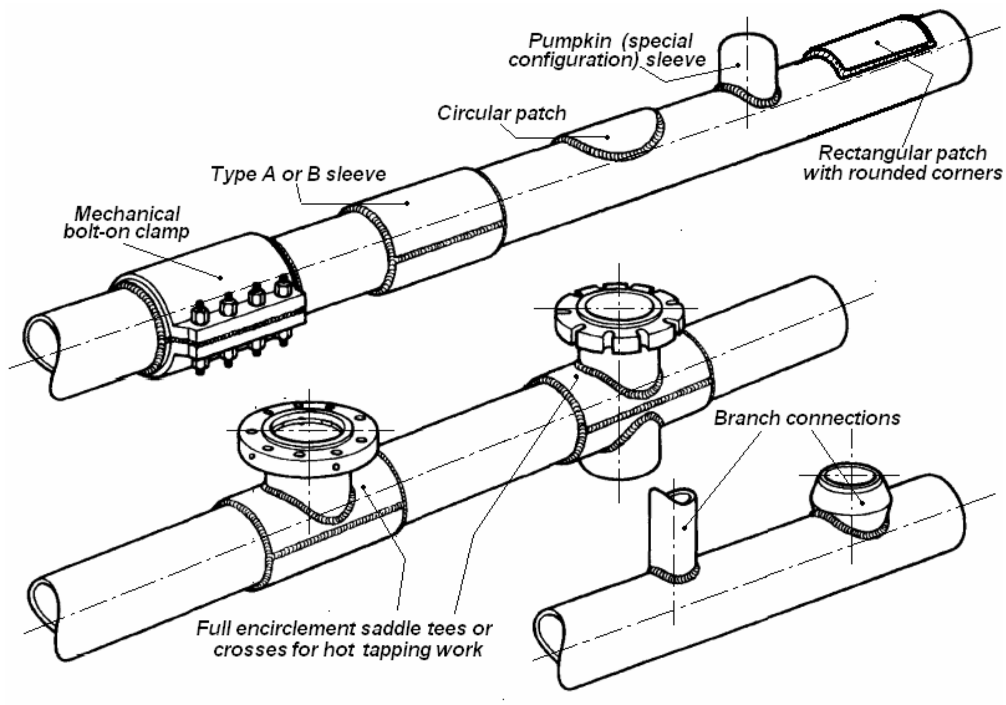

Fig. 2. Main types of additional elements that can be applied when performing maintenance works for transmission pipelines

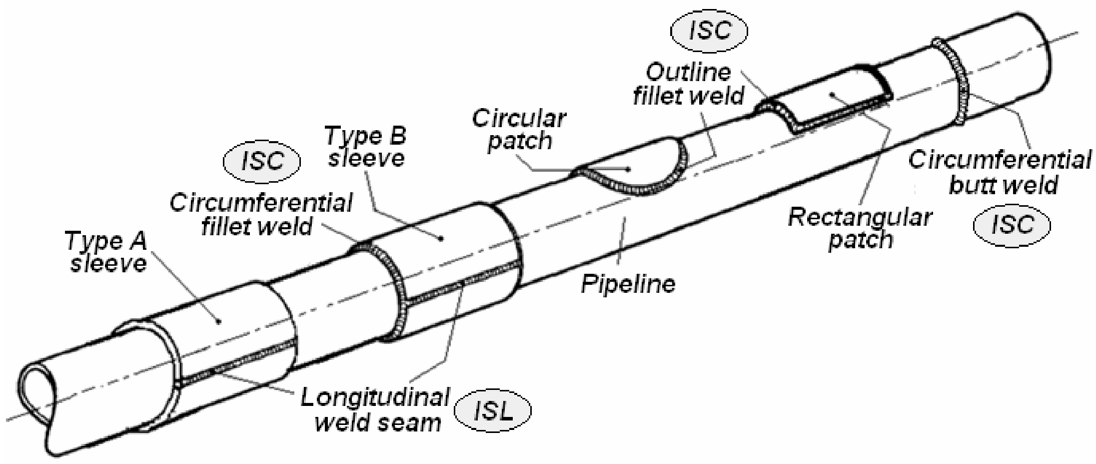

Fig. 3. Main types of welded joints carried out when repairing defective pipelines by various technological procedures

The valid norms [4] emphasize that when welding directly onto the in-service pipeline, two main issues have to be considered: a) Avoiding the burning through of the pipe wall by the electric spring used as thermic source while welding; b) Avoiding the hydrogen induced cracking (also known as cold cracking or delayed cracking), which is strongly activated by the fast cooling of the pipe wall in the welding area, produced by the passing of the fluid under pressure with a certain speed within the pipeline.

As it is specified in Annex B from [4], the burning through of the pipe wall by the electric spring used as thermic source when welding is unlikely, if the effective thickness *s* of the wall fulfils the condition $s \geq 6{,}4$ mm (0, 25 in) and if there are used for welding low hydrogen wrapped electrodes (of EXX18 type) and usual welding technologies (from the point of view of the size of the welding heat input). On this basis it can be estimated that the fulfilment of the condition $s \geq 6{,}\ 4$ mm (0, 25 in) is the first premise which has to be considered in selecting the maintenance technologies for welding (referring to ISC type joints) onto pressurized pipelines. Figure 4 shows the flow charts (experimentally drawn up) of the heat input when carrying out the welding operations onto crude oil and natural gas transmission pipelines [5].

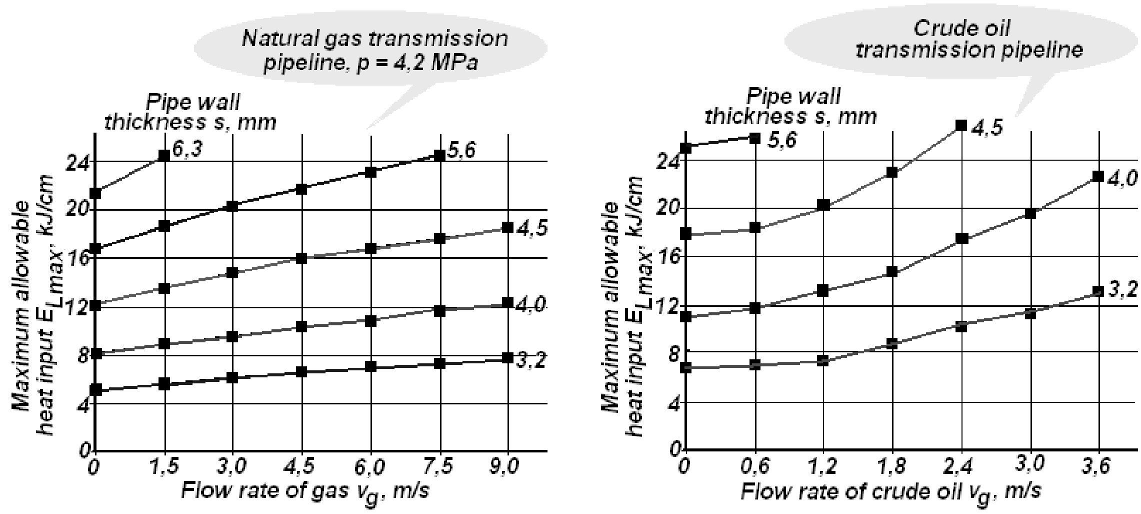

Fig. 4. Flow charts for selecting the heat input for avoiding the burning through of the pipe wall by the electric spring used as thermic source while welding

The hydrogen induced cracking takes place if the following conditions are simultaneously fulfilled: a) There is hydrogen in the welded joint; b) The welded joint reveals areas with a structure liable to cracking; c) In the welded joint there are generated tensile stresses. Consequently, to avoid this, when conceiving the welding technology for the pressurized pipelines one must first pay attention to the use of low hydrogen electrodes and to the setting up of the conditions necessary to carry out these welding procedures with low diffusible hydrogen in the welded joints. If these conditions can not be assured, there must be applied measures to minimize the possibility of the appearance in the welded joint (in the CUS and in the heat-affected zone – ZAT) of some microstructures sensitive to cracking. The most efficient procedures that can be adopted are: the use of a welding heat input which is high enough to counteract the effect of fast cooling the fluids under pressure have in the pipeline subjected to welding, the welding with preheating (when this method can be applied and the effects of fast cooling produced by the circulation of the fluids in the pipeline do not hinder the reaching of the expected level of the preheating temperature), the deposition of some narrow beads onto the ground of CUS in the corner, onto the surface of the pipe wall, with additional materials which confer to these a low yield strength and a high plasticity (the solution is called synthetically "temper bead technique"), as shown in figure 5. Finally, to assure low intensities of the generated residual stresses and the low concentration effect of these stresses at the root of the performed welded joints, there must be used adequate solutions (devices) for positioning and fixing for welding the additional elements applied onto the pipeline.

The success of performing some welding operations on the pressurized pipelines is directly determined by the providing of a balance between the safety measures (for avoiding the burning through of the pipe wall) and the measures able to forestall the formation of some non-corresponding structures of the welded joints. For instance, if the pipeline the welding is made onto has a thin wall ($s < 6{,}4$ mm), the selected level for the welding heat input must be limited (in order to minimize the risk of burning through the pipe wall), but this measure can lead to some high cooling speeds of the welded joint and to the growing of the risk of hydrogen induced cracking, which can be kept on a reasonable level only if some additional technological measures are selected, such as the use of low hydrogen electrodes.

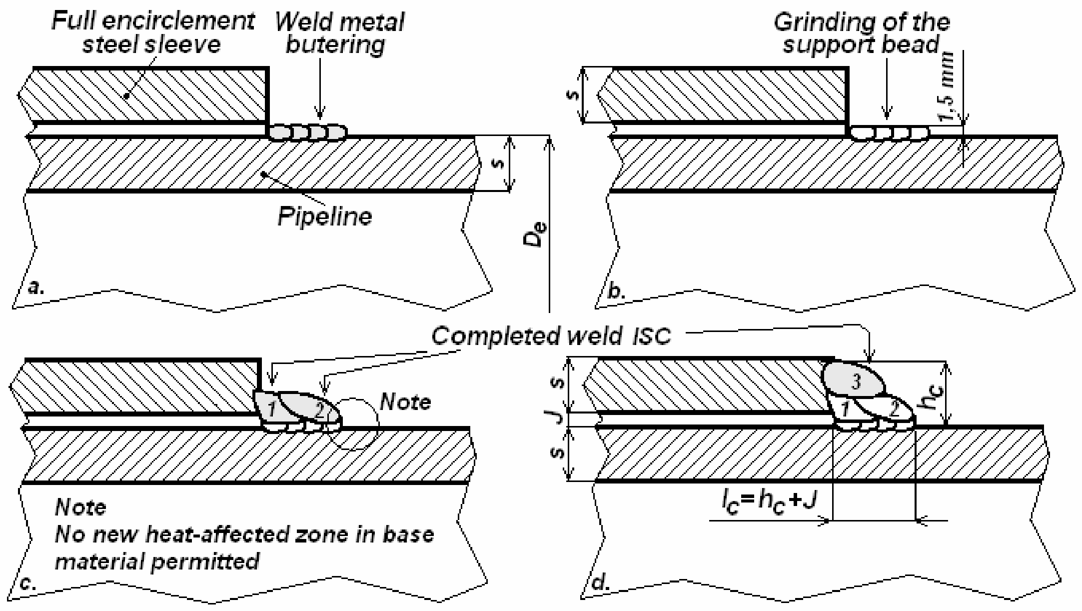

Fig. 5. Technology for carrying out the girth welded joints while repairing the pipelines with sleeves

When elaborating the Welding Procedure Specifications – WPS for welding directly onto pressurized pipelines, there must be taken into account the following aspects:

- The procedure must contain the following information: a) the main characteristics of the material (steel) the pipeline is made of and the additional elements applied onto it by welding: the minimum yield strength $R_{t0,5}$ and the value of the equivalent carbon C_e (or the groups considered for the levels of the equivalent carbon); b) the operating conditions (groups of conditions) for the pipeline to be welded onto (the fluid which passes through the pipeline, the operating pressure and the fluid flow rate etc); c) the interval of the welding heat input and the procedure for controlling the level of this heat input; d) the steps of performing the passes and beads of the welded joints.
- The procedure must specify the essential variables and when modifying these variables there must be elaborated a new procedure; Annex B a [4] makes the following specifications regarding the variables that interfere in the direct welding of pressurized pipelines; a) for the fillet joints (such as ISC which are carried out within maintenance operations), the specified minimum yield strength $R_{t0,5}$ and the wall thickness s are not essential variables; b) the operating conditions of the pipeline to be welded onto (which determines the modification of the cooling conditions of the welded joints), the order and the way of deposition of passes and beads of the welded joints, inclusively of the annealing passes, are essential variables.
- The procedure must stipulate the adequate welding conditions in order to assure the performing of welded joints with no risk of hydrogen induced cracking; the minimum welding heat input, with or without preheating, is established using complex flow charts, like those shown in figure 6, drawn up experimentally or by numerical simulation [2,5].
- The procedure must stipulate precise recommendations regarding the welding practice: a) before welding, the welders must know in detail the operating conditions of the pipeline (the pressure of the transported fluid, the flow conditions of the fluid, the fluid's temperature) and the wall thickness in the area the welded joints will be placed on; b) the sleeves or wraps mounted onto the pipelines must have an adequate shape and precise sizes, so that there are not too large free spaces between the additional elements and the pipe (if the free spaces are to large, they can be diminished by the deposition of two annealing beads on the support pipe) or

non-uniformities; c) ISL, which is performed between the semi-cylindrical elements of the additional elements (sleeves, wraps, etc) applied onto the pipeline, must be carried out preferably without affecting the pipe wall (by preparing the edges of the components by butt welding, as shown in figure 7 [2,6] and by selecting some technological run-on and run-off plates for the electric spring); d) the methods for checking and testing the quality of the ISC must be able to emphasize the possible presence of crack-like flaws in welded joints.

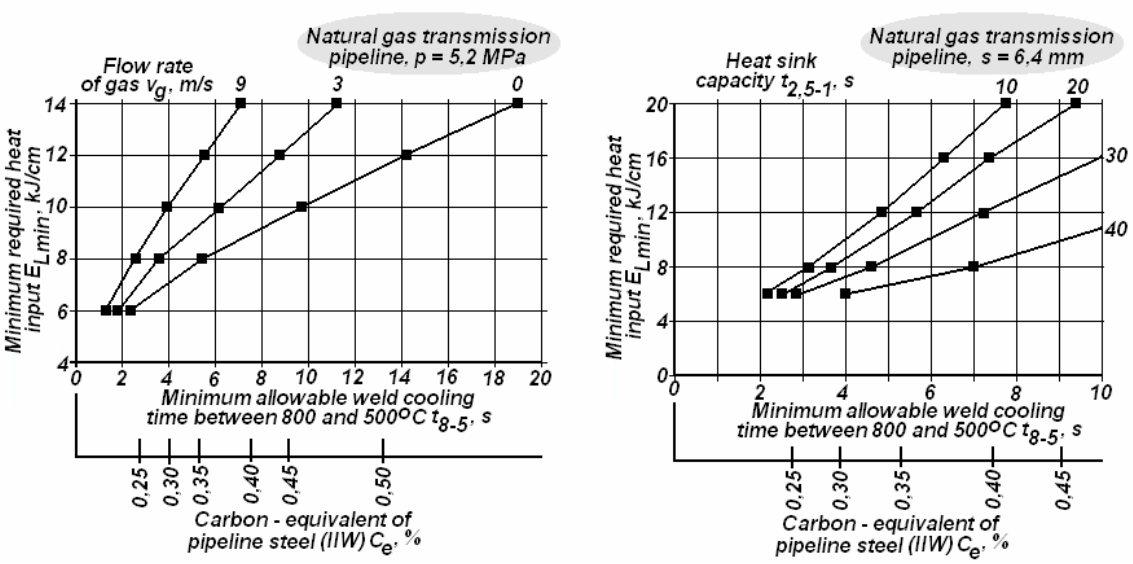

Fig. 6. Flow charts for establishing the welding conditions when performing maintenance works for pressurized pipelines

Particularities of Repairing Pipelines with Composite Wraps

The repair works by means of complex wraps, carried out with composite materials, represent a modern class of technological repair procedures for pipelines with local shallow flaws, such as “metal loss”, produced by corrosion or defects such as dents, (generally) produced by the interferences of third parties. The technological procedures of this class allow the repairing without taking the pipelines out of service and without welding operations.

The procedures of this class consist of applying in the defective area of a wrap with complex structure, which consists, as it can be seen in figure 8, of the following components: a polymeric filler (filling material) – PF, used for covering the defects on the pipeline and remaking its outside configuration, more strip layers of composite material – TW, made up of a polymeric matrix – PM and hardening fibres which can be continuous fibres, discrete fibres or fibre textures of glass or graphite and a polymeric adhesive – PA, which enables the connection and the synergical co-action between the pipeline and the TW and between the successive layers of TW [7.8].

The procedures are very efficient, it was ascertained experimentally that the performed repair works by means of these procedures on pipelines with local defects such as “metal loss” with depths up to 80% of the pipe wall thickness, can remake and even increase the mechanical strength of pipelines and can assure a longer operating life of these. The wraps of this type, having various commercial names (Clock Spring – CS, Fiba Roll – FR, WrapMaster – WM, Snap Wrap – SW, Strong Back – SB, Black Diamond Composite Wrap – BDCW, ICECHIM Wrap Repair – IWR) allow definitive repairs and can be applied onto pipelines having an outer diameter between 101,6 mm (4 in) and 1422,4 mm (56 in). The productivity in performing such repair works is much higher than with any other method which requires welding operations; for instance, applying a CS wrap lasts 15 … 20 minutes and the finalization of the repair work, together with the reinforcement of the used fillers and synthetical adhesives and obtaining the maximum mechanical strength of the applied wrap doesn't take longer than 2,5 hours. [9,10].

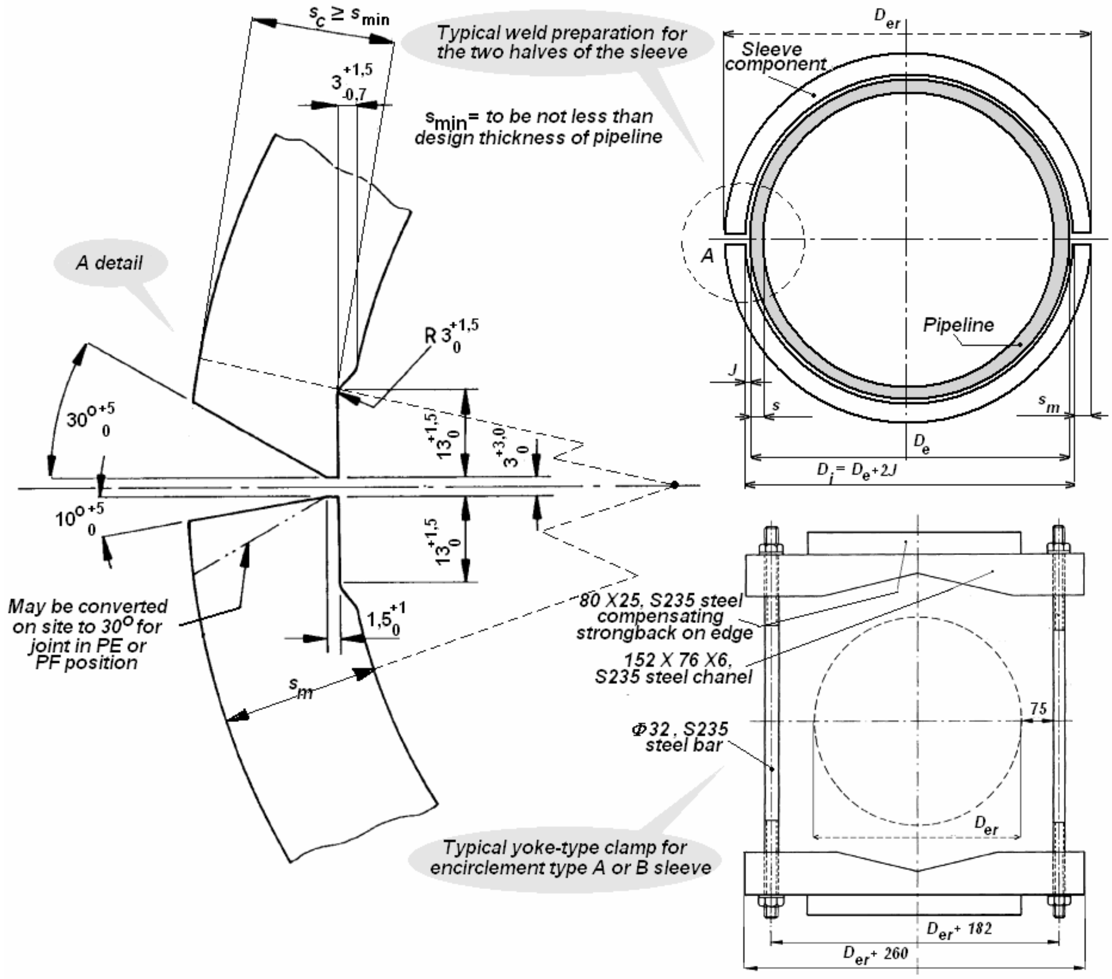

Fig. 7. Preparing for carrying out ISL of the sleeves' components used for repairing pipelines

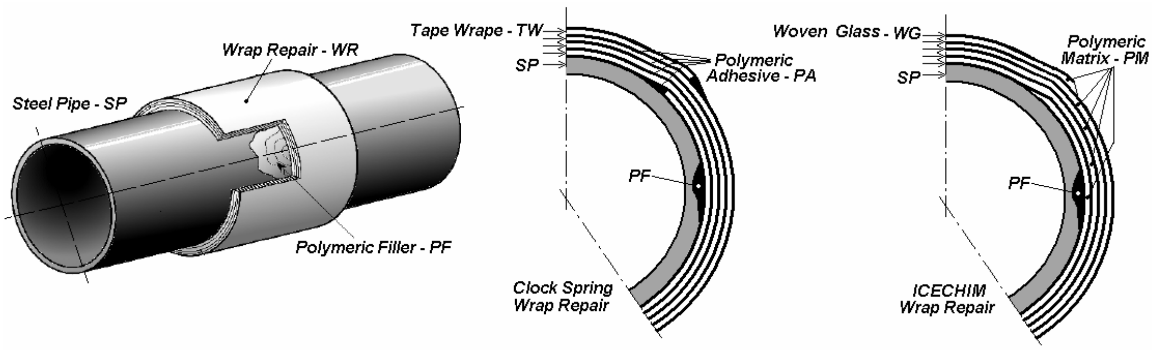

Fig. 8. The structure of the composite material wraps for repairing pipelines

The repair kit for a procedure as the above-mentioned has as main components the filler or the material used for filling the defect that has to be repaired and the composite material that makes up the pipeline consolidation wrap in the defective area, which consists either of successive strips of composite material (having a polymeric matrix and a reinforcement material) coupled together by means of an adhesive, or by a composite material made of more successive layers of reinforcement material, impregnated and coupled in order to co-act with a material of polymeric matrix type). As a consequence, the materials that contribute to complex wraps used for repairing pipelines are polymeric materials or composite materials fillers (materials for filling the defects) are made of and the wraps for pipeline consolidation in the defective area, the properties and performances of the repair works depending on their properties.

The application of the repair procedures by means of complex wraps is simple and requires middle trained staff, but requires also the taking into consideration and the strict observance of all the indications specified by the producer, the importer or the distributor of the repair kit in the Safety Data Sheet of each of the materials (substances, preparations, products) in this set, for which, according to the provisions of [11], such a document must be put at the disposal of the user, elaborated according to [12].

The repair technology for a pipeline by means of composite material consolidation wraps is simple, as it is shown in figure 9, which presents the steps of applying a composite material wrap of polymeric materials conceived by a research staff of ICECHIM Bucharest or a Plug-n Wrap "PLUS" [8]. Usually, before applying the consolidation wrap there has to be carried out a sand-blasting and a degreasing of the pipe in the defective area and the defects are then covered by a filler, in order to remake the configuration of the outside surface of the pipeline.

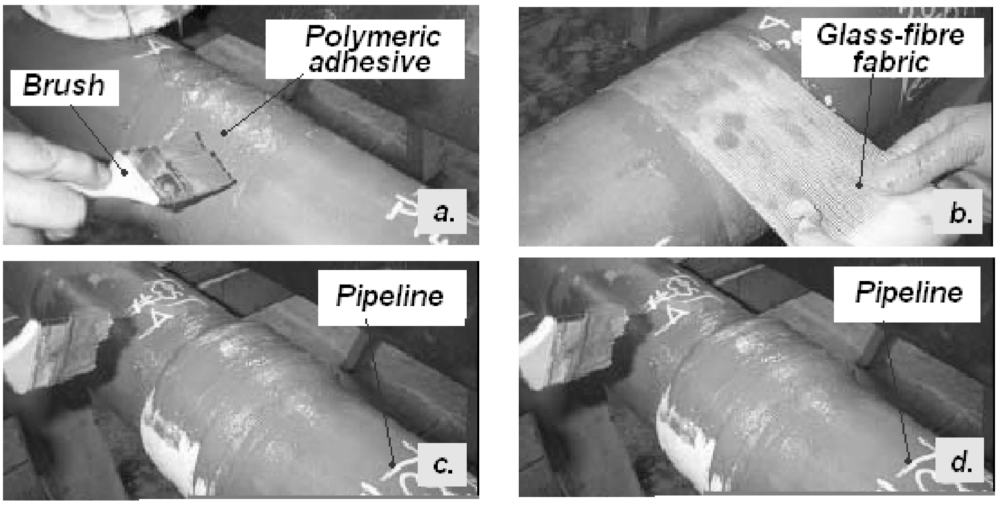

Fig. 9. The technology of applying composite wraps with polymeric matrix and glass fibres

Table 1. Mechanical features of the composite materials used for repairing pipelines

Composite material	Reinforcement material of the composite	Mechanical properties of the composite material**		
		E_C, GPa	R_{mC}, MPa	A_C, %
IWR	Glass fibres	17.5...22.7	265...315	1.32 ... 1.60
Perma Wrap	Glass fibres	34.0 … 38.0	580 …620	1.00 … 1.10
Fiba Roll	Glass fibres	7.9 ... 8.7	86 ... 72	2.60 ... 3.10
Clock Spring	Glass fibres	33.8 ... 34.5	630 ... 650	1.06 ...1.36
TDW RES-Q Wrap	Carbon fibres	65.5 ... 68.8	1000...1028	-

* measured in the direction which corresponds to the pipeline's circumference when applying the composite wrap

The composite materials used nowadays for consolidation wraps for the repair of defective pipelines have, as it can be seen examining the data synthesized in table 1, high mechanical characteristics. The mechanical strength R_{mC} of these composite materials is likely to the one of the steel-types the pipes are made of, but the elastic features (the modulus of elasticity E_C and the Poisson's ratio μ_C) and the elongation at failure A_C are inferior to those corresponding to the steel-types; the anisotropy of these materials is now removed by using reinforcement textures (of glass fibres or graphite) with tetraaxial texture (instead of the usual biaxial texture) [7-10,13-16].

The Quality of the Repair and the Criteria for Selecting the Repair Technologies

In order to emphasize the quality of the repair works performed by means of the above-mentioned technologies, it was resorted to the simulation by means of some analytical and numerical methods of in-service behaviour of the repaired pipelines [2]. The main criterion used for estimating the quality of the repair works was the configuration of the mechanical stress field and specific strains generated in the repaired area of the pipeline by the action of the transported fluid (described both by the distribution modulus, and by the maximum values of the stresses and strains).

The analysis by numerical simulation by mean of the finite element method – MEF of the performed repair works by applying a B-type sleeve onto the pipelines that have outer shallow defects led to results as those synthetically shown in figure 10 [2,13]: a) if the repair works are performed by the simple application (by welding) of a B-type sleeve, the state of the stress is not favourable, the maximum stresses generated in the in-service pipeline being localized in the wall of the defective pipe and at the ISC root, while the applied sleeve is very little loaded; b) if in the interstice between the used sleeve and the pipe's wall there is introduced a coupling material (a polymeric material or a composite aggregate), the state of the stress modifies, the applied sleeve efficiently taking over the mechanical loads and the stresses in the consolidated area of the pipeline being less than those generated in the areas of the pipeline which are not affected by the repair work.

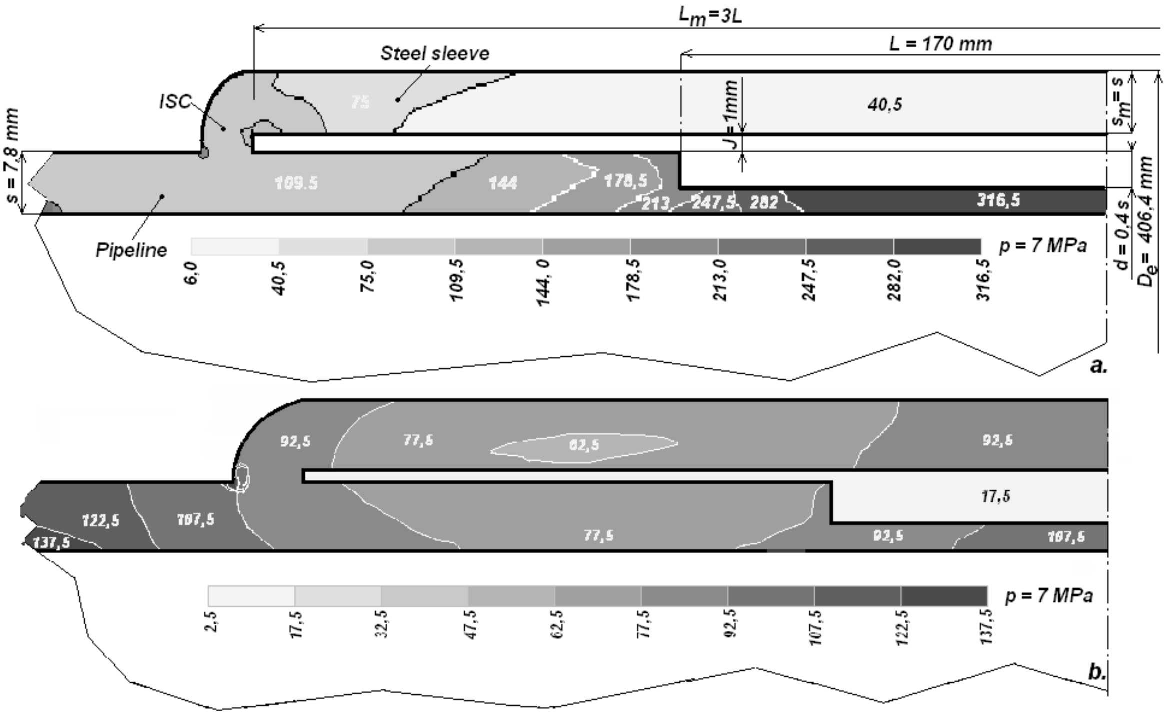

Fig. 10. The mechanical stress field generated in the area of the repair works with welded sleeves

a. the empty interstice between the pipeline and the sleeve;

b. the interstice between the pipeline and the sleeve filled with resin

The analysis by analytical and numerical simulation of the performed repairs by applying a composite material wrap onto the pipelines with outer shallow defects led to results as those shown synthetically in figure 11 [1,8]: a) the capacity of the coating to take over the mechanical loads of the pipeline depends essentially on the value of the elasticity modulus of the composite material it is made of, as its value increases, the thickness of the coating necessary for repairing the defective pipeline decreases and, consequently, the wrap becomes more efficient; b) the best consolidation capacity of defective pipelines is assured by the repairs made with steel coatings filled with polymeric or composite materials.

Following the analysis performed it obviously results that the solution recommended for repairing pipelines is the application of metallic wraps filled with polymeric or composite materials (the technologies codified *0011 – 07* and *1011 – 07*). The application of the outer metallic wrap doesn't require welding operations directly onto the pipe to be repaired and the polymeric or composite material introduced in the interstice between the metallic wrap and the pipeline assures the efficient mechanical coupling of the metallic components and increases the consolidation capacity assured by these.

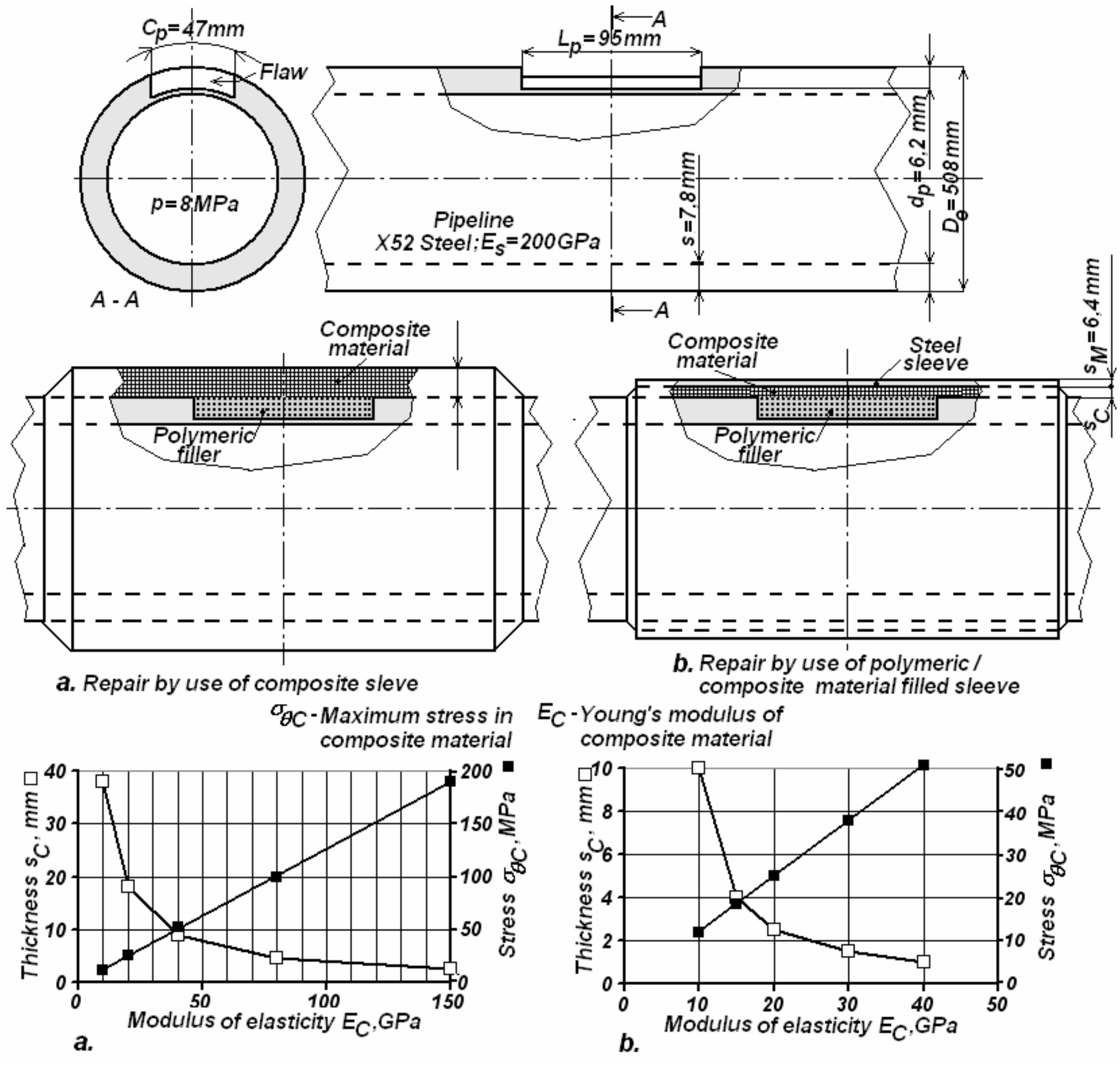

Fig. 11. The characterization of the consolidation capacity and the efficiency of the repairs carried out by applying composite material wraps

Conclusions

For repairing fuel fluid transmission pipelines (crude oil, liquid petroleum products and natural gas) there can be used both technologies that require welding operations and repair technologies without welding, by applying composite material consolidation wraps.

For repairing pipelines without taking them out of service there are preferred technologies that don't require welding directly onto the pipe work, because the technical risk when doing this is high and performing this requires the elaboration and qualification of adequate welding procedures and the rigorous observance of these.

A simple and safe solution for repairing pressurized pipelines is the application of composite material wraps, but the use of these seems to be inefficient because for obtaining the expected consolidation effects there are necessary wraps having a big thickness (which imply high costs).

The comparative analysis of the quality of the repairs carried out by means of the technologies shown in this work highlighted the fact that a safe and efficient solution for repairing pipelines can be the repairing with metallic wraps filled with polymeric or composite materials, whose application doesn't require welding operations directly onto the pipe work and doesn't imply high consumption of polymeric or composite (expensive) materials.

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Tehnologii de reparare a conductelor sub presiune

Rezumat

În lucrare sunt analizate comparativ tehnologiile de reparare a conductelor destinate transportului fluidelor combustibile (petrol, produse petroliere lichide şi gaze naturale) cu şi fără operaţii de sudare. Sunt evidenţiate avantajele şi dezavantajele tehnologiilor de reparare bazate pe aplicarea prin sudare a unor elemente de adaos (manşoane, petece) şi a celor bazate pe aplicarea de învelişuri din materiale compozite. De asemenea, se prezintă criteriile de selectare a tehnologiilor de reparare (cu şi fără operaţii de sudare) la repararea conductelor sub presiune.