NON DESTRUCTIVE TESTING OF PIPELINES STATE AND METHODS FOR ITS REPAIRING

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The paper presents some materials, related with projects, realization, nondestructive testing examination and repairing of the pipes during exploitation.

This report is prepared on the base on some papers [2, 3, 5, 6, 7, 8], presented during the 2-nd South East European IIW International Congress and firm information about NDT procedures and devices.

1. Current conditions and future pipelines

1.1. Potential gas supply to Europe to 2030

Presented in Table 1 data is based on the work carried out by Observatoire Méditerranéen de l’Energie (OME) in the framework of the ENcouraged (Energy Corridor Optimization for the European Markets for Gas, Electricity and Hydrogen) project financed by the European Commission DG-Research 6th Research and Development Framework Programme [1].

Table 1 Gas supply potential to Europe-34 by exporting country, projection to 2030

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(1) Russia exports in 2005 include 4 bcm from former FSU Republics
(2) The assumption made in this study is that Kazakhstan, Turkmenistan an Uzbekistan will not be able to sell their gas directly to European markets but rather to Russia which could resell part of it to Europe. Central Asian gas exports have therefore been accounted for in the Russian export potential.
Source: CEDIGAZ (2005 figures) and OME (projections)
Figure 1. Gas export potential to Europe-34 of the main producers

Figure 2 presents Russian gas supply to Europe

Figure 2. From Russia to Europe: Natural Gas Pipelines
1.2. Projects in Balkan region
The present and the main potential suppliers for the European region at the moment are:
• from North Sea – whose deliveries potential decrease;
• from Algeria – at the moment main destiny is Italy;
• from Russia - by means of pipelines across Ukraine, Belarus and Turkey.

The increase of the delivery potentials is associated with:
• Russia with the new projects North Stream and South Stream
• The Caspian region states – Aserbaydzhan, Turkmenistan and lately Iraq with the projects Nabucco and AGRI [2].

The above presented disposition of the gas suppliers was a basis of agreement to start the preparation and realization of the two mega-projects for gas supply of West Europe, namely South stream and Nabucco.
Figure 4. The general configuration scheme of the Nabucco pipeline project

Figure 5. The general configuration scheme of the South stream pipeline project

Figure 6. The Black sea branch of the South stream pipeline project
1.3. Materials used for pipelines
In pipeline building history, mainly three types of steel pipelines have been used:

- up to Ø 325 mm – by means of seamless pipes
- up to Ø 1000 mm - by means of spiral seam or straight seam pipes
- up to Ø 1400 mm – by means of straight seam pipes.

In the near past, X52 and X65 steel of different alloy scheme pipes were used. Since the past century’s 80s, elevated strength steels started being more and more often applied for the pipelines, such as X70, X80, and today, pipelines of X100 steel are tested.

This tendency was imposed by the necessity to optimize the costs for main pipelines over great distance.

The weight difference alone between pipelines of e.g. X60 and X80 steels results in huge economy of metal units over great distances. In the same time, lighter pipes require lighter mounting technique (pipe-layers).

1.4. Welding technology and non destructive testing of pipelines
In the period before 1975, the basic welding technology was associated with application of MMA process and joining together three pipe sectors in preliminary manufacturing stations through rotation under submerged welding process. This MMA approach was considerably developed further on, when cellulose shield electrodes were applied to implement the weld root. This ensured weld root defect removal, but raised strong requirements towards the welding technology considering setting free the hydrogen from the weld. The requirements towards the welder qualification and towards the welding joint NTD control were also raised.

To overcome those problems, multi-positional MAG equipment for orbital welding of the Company CRC - Huston was introduced.

NDT control during the erection manufacturing process is take significant interest.

Quality is extremely important for flawless and long time gas pipeline exploitation. Some failures may cost tens of millions Euro. Direct and indirect damages could be incurred. Therefore, there should not be any compromise in NDT and it should permanently be following the front welding groupe.

Figure 7. A view of the CRC technology execution
2. International standardization in the field of welding and NDT

The development of new and the revision of existing ISO Standards in the field of welding and allied processes was formidable in the last five to seven years. In the middle of the year 2009 there were available more than 300 European and more than 270 International Standards in that field, most of the EN Standards are identical or very similar to ISO Standards. Industry has to take into account the new standards and the changes in the existing once especially in respect of filler materials, procedure qualification tests, personal qualification, non destructive tests and requirements to manufacturing joined products. There is a strong relation of these standards to product standards and to European Directives [3].

Technical standards are developed on different levels: on national, on regional and on international levels (Fig. 9). The national level does not need any interpretation. Although some national standardization organizations have a strong international impact like ASME, API and AWS of the U.S. in the corresponding branches.
The regional levels are e.g.

- African Regional Organization for Standardization (ARSO)
- Arab Industrial Development and Mining Organization (ARSO)
- European Committee for Standardization (CEN)
- Pan American Standards Commission (COPANT)
- Euro Asian Council for Standardization, Metrology and Certification (EASC)
- Pacific Area Standards Congress CP ASCI
- ASEAN Consultative Committee for Standards and Quality (ACCSQ)

European standards are developed by CEN, the European Committee for Standardisation, CENELEC, the European Committee for Electrotechnical Standardisation, both with then-central offices in Brussels, and ETSI, the European Telecommunications Standards Institute with its central office in France.

In this contribution mainly will be dealt with international standardisation activities by ISO, the International Organisation for Standardisation. ISO collaborates with its partners in international standardisation, the International Electrotechnical Commission (IEC) and the International Telecommunication Union (ITU). The three organizations, all based in Geneva, Switzerland, have formed the World Standards Cooperation (WSC) to act as a strategic focus for collaboration and the promotion of international standardization.

The international standardization work in the field of welding and allied processes mainly is done in ISO TC 44 "Welding and allied processes". The secretariat is with AFNOR, the French national standardisation organisation, and chairman is Mr. Lobinger, from France as well.

The scope of ISO/TC 44 reads: "Standardization of welding, by all processes, as well as allied processes; these standards include terminology, definitions and the symbolic representation of welds on drawings, apparatus and equipment for welding, raw materials (gas, parent and filler metals) welding processes and rules, methods of test and control, calculations and design of welded assemblies, welders' qualifications, as well as safety and health. Excluded: electrical safety matters related to welding which are the responsibility of IEC / TC 26”

| WG 1 | Underwater welding (dormant) |
| WG 3 | Brazing materials and processes |
| WG 4 | Welding and brazing in aerospace |
| SC 3 | Welding consumables |
| SC 5 | Testing and inspection of welds |
| SC 6 | Resistance welding and allied mechanical joints |
| SC 7 | Representation and terms |
| SC 8 | Equipment for gas welding, cutting and allied processes |
| SC 9 | Health and safety |
| SC 10 | Unification of requirements in the field of metal welding |
| SC 11 | Qualification requirements for welding and allied processes personnel |
| SC 12 | Soldering materials |

At the actual stage ISO/TC44 and its subcommittees (SC) are working on 51 projects. These are revisions of existing standards and developments of new standards. Most of these projects are handled in a strong cooperation with CEN, the European Committee for Standardisation, following the Vienna Agreement to avoid as far as possible different standards on the same subjects on the European and the international level. Anyway there are some projects that are on European but not on international interest. These projects are handled only by CEN/TC 121 “Welding and allied processes” and its subcommittees.
3. Non destructive testing of pipelines

Pipelines are essentially pressure vessels and lack of pipeline integrity can lead to failures, which can result in significant financial loss, not to mention environmental damage and detrimental effects on a company’s reputation. Accurate and adequate inspection is the key to assessing pipeline integrity by the latest technology available for this critical task – from the manufacture of the pipe through construction to aging asset.

Many factors can affect the integrity of a pipeline throughout its entire life cycle. Although flaws within the original steel plate used to fabricate pipes are rare, 100% ultrasonic testing is still carried out prior to rolling. After rolling, the longitudinal or spiral welds of the finished pipe must be inspected for defects such as cracks, slag inclusions, lack of fusion, porosity, etc. Similarly, base material defects can occur in the heat-affected zone (HAZ) and it is important to inspect the pipe ends, as these will become the HAZ during pipeline construction. Girth welding, where lengths of pipe are joined together often takes place in less than hospitable conditions, ranging from an exposed double joint fabrication yard to the back end of a lay barge. As a result, the equipment used to carry out inspection must be robust and flexible as well as accurate and reliable. In-service inspections for integrity not only look at welds but also monitor corrosion/erosion, caused by aggressive or abrasive fluids or environments. In addition, environmental conditions can
Sometimes cause embrittlement and stress corrosion cracking of welds and base metals.

Naturally, each of these inspection areas poses its own particular challenges and this has resulted in the development of application-focused solutions [4].

3.1 Non-destructive testing during the manufacturing process

3.1.1. Base NDT methods

Most pipe mills include some kind of inspection after virtually every stage of manufacture. Steel plate is inspected by the supplier of the raw material and documented results are provided with each shipment. Testing machine are integrated into pipe production lines and are used to test a wide range of tubes and pipes, from small diameter, cold finished, seamless tubes for power plants or automotive the industry, to large diameter, large wall thickness hot rolled seamless tubes for casing and drill pipe and welded tubes for oil and gas pipelines. Inspection is carried out by a variety of methods including visual inspection, eddy current, flux leakage, magnetic particle inspection, radiography and ultrasonic inspection. Visual inspection is generally carried out after submerged arc (SAW) welding or electronic resistance welding (ERW) of the long seam to identify any obvious manual pipe welds and base metals.

Historically, girth weld inspection has been carried out by radiography. For both small and large diameter pipes. This technique provides easy-to-interpret, two-dimensional grayscale images of the weld and, with minimal training; an operator can interpret the image and determine the relative quality of the weld. While radiography is still widely accepted, like any other technique, it does have its drawbacks and disadvantages, especially in terms of creating radiation hazards.

Moreover, traditional radiography creates a two dimensional image or picture of a weld, normal to the radiation source. As a result, weld cracks oriented perpendicular to the surface are often not detectable and present a possible failure mode if unchecked. Conversely, X-ray inspectors, simply because of a lack of adequate three dimensional inspection data, sometimes reject perfectly acceptable welds.

3.1.2. Advanced ultrasonic method

The automated ultrasound techniques have been gradually replacing the radiographic methods all over the world. Advanced ultrasound systems have been developed in order to improve the inspection efficiency [5]. The API 1104 defines some requirements to be fulfilled during the ultrasonic testing, like the type of sensitivity blocks to be used, the scanning sensitivity and the evaluation level. However, the code doesn’t define rigid rules about how the inspection shall be performed.

Issued in 1998 a standard practice ASTM E-1961 (ASTM E1961 - 06 Standard Practice for Mechanized Ultrasonic Testing of Girth Welds Using Zonal Discrimination with Focused Search Units) establishes some recommendations for the mechanized ultrasonic examination of pipe girth welds. This practice describes a methodology in which the weld volume is split in thin slices, each one with a height approximately equal to one filler pass height. Each zone will be inspected independently from the adjacent zone, in order to allow having a precise dimension of the discontinuity height.

Although this practice was originally developed for ultrasonic inspection using several monolithic focused probes, the same principle can be applied to the automated ultrasonic inspection system.

In this context, here it is presented an automated and integrated ultrasonic inspection system combining Phased Array and TOFD (Time Of Flight Diffraction) techniques. Although TOFD is not recognized by API 1104, has great advantages like the ability to improve the indications sizing (length and height) as well to assist the NDT operator for the interpretation of the geometric features in the root region, like root concavity, excess of penetration, weld misalignment, that are very difficult or even impossible to assess using pulse echo techniques. As disadvantages TOFD has a presence of dead zones mainly in the OD surface, and a poor spatial resolution in depth from the OD surface up to the first third of the thickness. However the Phased Array module overcomes this disadvantage [5].

Most conventional ultrasonic inspections use monocrystal probes with divergent beams which mean that the beam is not focused. The ultrasonic field propagates along an acoustic axis with a single refracted angle. The divergence of this beam is the variable that will contribute to detection and sizing of misoriented defects.

In the case of Phased Array technique, it is assumed that the monoblock is cut in many identical elements, each with a width much smaller than its length. Each small crystal may be considered a line source of cylindrical waves and according Huygens principle a new wavefront of the new acoustic block will constructively interfere, generating an overall wavefront. The small wavefronts can be time-delayed and synchronized for
phase and amplitude, in such a way as to create an ultrasonic focused and/or driven beam with steering capability. The main feature of phased array ultrasonic technology is the computer controlled excitation, in terms of amplitude and delay, of individual elements in a multi-element probe. The excitation of the different piezocomposite elements can generate an ultrasonic focused beam with the possibility of electronic modifying the beam parameters such as angle, focal distance, and focal spot size through software.

The sweeping beam is focused and can detect in specular mode the misoriented cracks. These cracks may be located randomly away from the beam axis. A single crystal probe, with limited movement and beam angle, has a high probability of missing misoriented cracks, or cracks located away from the beam axis, Fig. 11. [5]

Regarding the second advanced ultrasonic technique used in the system presented in this paper, Time Of Flight Diffraction (TOFD), the most significant distinction between this technique and the other UT methods is that it monitors the forward-scattered diffracted energies, relatively low amplitude signals, only from the tips of defects rather than reflected ultrasonic energies. Two wide beam angle probes are used in transmitter-receiver mode and the distance of the probes is calculated according to the wall thickness. Broad beam probes are used so that the entire crack area is covered by the width of the ultrasound beam and, consequently, the entire volume is inspected using a single scan pass along the inspection line. At the tips of the flaw the acoustic beam is diffracted and in some situations reflected and the diffracted signal is redirected to a receiver probe. At some generated time and due to the beam aperture, the lateral wave propagates along the surface, the back wall echo reflects the bottom surface of the test object and reach to the receiver. The other two signals, upper flaw tip diffracted signal and lower flaw tip diffracted signal appear due to the presence of a discontinuity, Fig. 12.

![Figure 11. Detection of misoriented cracks by monocrystal (left) and multielement probes (right). The beam is divergent and unidirectional for the monocrystal probe, while it is focused and multiangled for the phased array probe. Cracks of most orientations can be detected by the phased array probe][5]

![Figure 12. TOFD principle][5]
Concerning the modelling stage, in each zone a focal point was associated with a specific angle and focal distance. Fig. 13, illustrates one typical configuration for a V bevel weld with a thickness of 9.5mm. In this case the weld volume was split in 5 regions.

After the system setup and calibration the validation trials were performed. For this purpose a pipe sample of 20" and 9.5 mm of thickness was used. This sample was also inspected trough radiography with a Se75 source and a C5 film in panoramic exposition, and the both results were compared. The Fig. 14 shows an example of these results related to a crack (left side) and a lack of fusion (right side).
Regarding the porosity, the TOFD module is able to detect this type of defect. As the API does not consider this technique to evaluate the defects, at this stage this module is used as complementary information to the Phased Array. In any case, the TOFD module has an important added value in the integrated system, because its information can be used to validate the welding process.

The system was also tested in field in a gas pipeline of 12”. The inspection results of 250 welding joints were simultaneously compared with radiography (Crawler) using a Se75 source. As can be observed in Table 4 the results obtained with the Automated Ultrasonic system (AUT) in terms of inspection capabilities were considerable better than those obtained with the conventional systems based in the radiography.

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</table>

Table 4. Results of the validation tests between radiography (Se75) and the ultrasonic system

The Figure 15 shows the system operating in real environmental conditions.

Figure 15. Gas Pipe inspection using the integrated inspection system

Firms SONOTRON NDT and RTD offer analogous equipment.

3.2. NDT during operation

In-service inspection is essential to extend the life of aging assets, to squeeze ever more production out of assets by minimizing downtime and to help prevent catastrophic failures, failures that can result in the loss of life, and damage to the environment and company reputation, and eventually company profits.

The occurrence of corrosion, erosion and mechanical damage to pipes and pipelines means that there is great interest in advances in methods of inspection. Of particular importance are improvements in the speed of inspection, tool accessibility, inspection range and costs.

3.2.1. NDT with pigs and crawlers

The need for pipeline non-destructive testing (NDT) grew very rapidly with the increase of offshore gas and oil exploitation in the 1970s. New pipelines for offshore supplies brought new and sometimes unexpected corrosion problems. The
presence of sediment and chemicals in offshore risers often caused corrosion and erosion of the risers, leading to wall thinning at several times the expected rate. The consequence of this was that expensively laid pipelines would fall short of their design lives [6].

Very substantial investments were made in the 70s in the development of both pipeline pigs for electromagnetic and ultrasonic detection of wall thinning, and X-ray crawlers for weld inspection in long runs of pipe. The perceived economic importance of these techniques at the time is evident from the publicity they received. The first smart pig was developed in 1964 using Magnetic Flux Leakage (MFL) technology to inspect the bottom portion of the pipeline (Fig. 16).

Figure 16. A ‘pig’ used to clean natural gas pipelines

Pigs and crawlers excelled at the time in being the only means of inspecting for erosion, corrosion and other types of defect in pipes buried inaccessibly below ground or on the seabed and/or encased in concrete or other protective coatings to protect outer pipe walls from corrosion. Pigs and crawlers excelled at the time in being the only means of inspecting for erosion, corrosion and other types of defect in pipes buried inaccessibly below ground or on the seabed and/or encased in concrete or other protective coatings to protect outer pipe walls from corrosion. Both approaches have the capability to inspect long lengths of pipes and pipelines in a short period of time. These pipes and pipelines do not need to be emptied for the inspection. However, not all the pipelines can be inspected in this way. Entry and exit points may not be present for the ‘pig’. Pipe bends or steep gradients may occur, which prevent the ‘pig’ passing through. There are therefore very large proportions (perhaps as high as 75%) of pipelines that cannot be inspected with the ‘pig’.

3.2.2. NDT with guided waves (low-frequency ultrasonic testing)

Hence long runs of pipe have to be taken out of service and bypassed to allow inspection. The above problems have been overcome using the Guided Wave Inspection (GW).

Over the past 10 years, TWI has been pioneering the technique of GW for corrosion and erosion detection and monitoring, which, in principle, allows inspection of long runs of pipe from just one access point. In this technique a pulsed guided wave mode is propagated in a pipe wall from a family of equally spaced ultrasound probes supported by a collar wrapped round the pipe. The wave is reflected from the pipe end, circumferential welds and defects in the wall, and the reflected echoes (usually mode converted) are received by the transmitting probes. Therefore, all defects in the entire run of pipe are detected simultaneously, provided they are large enough to produce an echo amplitude above the random noise level [6].

The promise of the technique as a global monitoring tool stems from the fact that low frequency guided waves have a very long range in pipes because:

(i) absorption in the pipe material is low at low frequencies.
(ii) for pipes in air, leakage of waves out of the pipe is very low because of the high acoustic impedance mismatch at the solid-air boundaries. Therefore, all the energy propagates down the pipe with little attenuation of the energy density (wave amplitude).
(iii) A wave mode with low dispersion (frequency dependence of phase velocity) can be selected so that the rate at which the wave pulse spreads out in time is small.

The test range can be defined as the range at which a defect which requires detection gives a detectable echo. So the probe collar need only be repositioned along the pipe at intervals equal to the twice the test range, with a small allowance for overlap to achieve total inspection coverage of an indefinite length of pipe. Depending on many factors such as pipe diameter, wall thickness and bend radius, as well as considerations (i) to (iii) above, the test range can be as much as 100 metres for an uncoated pipe in air.

TWI has exploited the long range ultrasonic technique through their subsidiary Plant Integrity Ltd. Figures 17, 18 and
Plant Integrity Ltd (Pi Ltd) tested Teletest to inspect caissons, on an offshore installation. Access to these caissons was difficult and Teletest had the ability to inspect the whole length of the Caisson from the top-side. The aim of the inspection was to test the full length of the caisson in order to gain an understanding of the condition prior to removal. This also allowed Plant Integrity to trial new analysis techniques such as focusing and the new Amplitude Map (A-Map).
A development of the technology and systems for remote flaw detection using a method of long-range low-frequency ultrasonic testing (LF UT) was significant progress in improvement of methods for control of technical state of extended objects.

PATON ELECTRIC WELDING INSTITUTE use advantage of this method at quick test of technical state of different application pipelines after their fitting through formation of initial defectogram of the pipeline as well as at their further monitoring and development of a database for calculation of operational life of the pipelines.

"LRUT" project according to this theme was carried out in the 6th Frame Program of EC in which the specialists from Ukraine, Bulgaria and other countries under the leadership of TWI took part [7].

A character of long-term operated extended pipelines is the presence of different internal or appearing on the surface reflectors in them. Classification of the types of reflectors in the pipeline and scheme of their possible positioning on the pipe is given in Figure 21.

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Figure 20. DAC curve for the caisson with A-Map

Figure 21. Classification of the types of reflectors in the pipeline (a) and scheme of their possible positioning on the pipe (b)
The piezotransducers of round form and star-shaped antenna, shown in Figure 22a, were used for study of the processes of distribution of twist oscillations in the pipeline. The antenna consists of two semicircles which are joined together mechanically during setting on the pipe, providing secure contact of semicircles with pipe surface. Each semicircle has four peaks on which four piezotransducers are installed, respectively. The piezotransducers though holes in their center are fastened to semicircle peaks, as a result of which a secure transfer of ultrasonic oscillations to antenna mass and pipe body is provided, respectively. At that, piezotransducer planes are directed along longitudinal axis of the pipe.

The small-dimension guided acoustic antenna with piezotransducers mounted in rubber circles are given in Figure 22b.

![Figure 22. General appearance of guided acoustic antennas](image)

An echogram of signals reflected from the pipe end, pipeline welded joints and from models of discontinuities are shown in Figure 9. The echogram was taken using guided wave of twist mode, which was excited with the help of star-shaped...
The signals given in the echogram show that pipeline welded joints are symmetric reflectors, therefore, they symmetrically reflect guided waves back to transducers’ circle. Such reflectors as corrosive damages are asymmetric reflectors and so induce conversion of the wave mode that allows differentiating them from welded joints.

4. Methods of pipelines repairing

For repairing natural gas transmission pipelines there can be used two technologies that require welding operations and repair technologies without welding, by applying composite material strengthening wraps [8].

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. The solutions shown below, regarding the choosing of welding conditions and technologies which lead to a safe performance of welded joints (by avoiding the burning through of the pipe wall by the electric arc used as a thermal source while welding) and to the obtaining of some quality welded joints (by avoiding the hydrogen induced cracking), can be of real help for those who perform maintenance works on natural gas transmission pipelines.

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 strengthening 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. The research of the technical performances of such solutions for repairing natural gas transmission pipelines represents one of the current concerns of the authors of this paper.

4.1 Welding on pressurized pipelines

As it can be seen in figure 25, applying the technological maintenance procedures for natural gas transmission pipelines may imply two types of welded joints: a) longitudinal weld seams – ISL, performed between semicylindrical components the steel reinforcing elements are made of; the performance of ISL does not significantly influence, thermally and metallurgically, the pipe wall, and the type of joints (butt or fillet welds) depends on the solution chosen while designing the weld jointed components; b) circumferential butt welds or outline fillet welds – ISC, performed for fixing (applying) on the pipework of some sleeves and patches used for repairs, as well as for joining on the pipeline the replaced sections; ISC are butt or fillet weld joints, and performing these affects directly and significantly, thermally, metallurgically and mechanically (by generating a residual stress field), the pipe wall [8].
4.2. Repairing pipelines by means of composite materials

The difficulties regarding the repair of pressurized pipelines using technologies that imply the performance of welding operations determined the search of repair technological solutions without welding, one of these is the application at the outside of pipelines, in the defective areas, of some reinforcing wraps made of composite materials.

Composite wrap repair has the structure shown in the Figure 26, and its achievement requires three stages: a) pipeline preparation for repair, which consists of cleaning the pipeline surface using an appropriate procedure and by operations of polishing, grinding or sand blasting in order to round the edges and smooth the flaws profile, eliminating the possible micro-cracks initiated on the flaws and the flaws transformation in long-radius curvature grooves, with reduced effects of mechanical tension concentration; b) pipeline external configuration rehabilitation, which consists of filling the outside flaws using a polymeric filler; c) pipeline mechanical strength rehabilitation, which consists of applying a composite wrap for reinforcement in the flaws area [8].

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 5, 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 $\mu_C$) 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) [8].
Table 5. Mechanical features of the composite materials used for repairing pipelines

<table>
<thead>
<tr>
<th>Composite material</th>
<th>Reinforcement material of the composite</th>
<th>$E_C$, [GPa]</th>
<th>$R_mC$, [MPa]</th>
<th>$A_C$, [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IWR</td>
<td>Glass fibres</td>
<td>17.5...22.7</td>
<td>265...315</td>
<td>1.32...1.60</td>
</tr>
<tr>
<td>Perma Wrap</td>
<td>Glass fibres</td>
<td>34.0...38.0</td>
<td>580...620</td>
<td>1.00...1.10</td>
</tr>
<tr>
<td>Fiba Roll</td>
<td>Glass fibres</td>
<td>7.9...8.7</td>
<td>86...72</td>
<td>2.60...3.10</td>
</tr>
<tr>
<td>Clock Spring</td>
<td>Glass fibres</td>
<td>33.8...34.5</td>
<td>630...650</td>
<td>1.06...1.36</td>
</tr>
<tr>
<td>TDW RES-Q</td>
<td>Carbon fibres</td>
<td>65.5...68.8</td>
<td>1000...1028</td>
<td>-</td>
</tr>
</tbody>
</table>

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REFERENCES:


