OFFSHORE OIL AND GAS: BRAZIL, PETROBRAS AND UNDERWATER WELDING

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Abstract

Oil and gas continue and will be an important supply of world's energy and materials, with current 30 % share of offshore exploration tending to increase along the years. And due to its remote and harsh environment, the offshore drilling of oil and gas especially in deep and ultra-deep waters requires huge investments with the employment of a multitude of personnel and operations involving very advanced technology. These are only possible for few major companies the world, among them it is Petrobras – Petróleo Brasileiro S/A. Regarding the relevance of the oil and gas industry in the energy matrix and of Brazil in this world scenario, this is an assessment of the most significant information available. It is mainly focused on the state of the art and challenges of the underwater welding, covering different scientific and technological aspects related to its process techniques and materials. It considers the differences of UW materials and process requirements for seabed pipelines and offshore structures regarding construction and repair with risks involved such as hydrogen induced cracking and porosity. More importantly, research institutions and related projects developed or under development in Brazil, together with related practices being used inside the Petrobras, is given herein as to outline the place and importance of underwater welding inside the oil and gas industry.

1. Introduction

As one of the largest and important industries in the world, the oil and gas industry includes a vast range of activities and businesses related to exploitation, production, refinement, transportation, and marketing. The economic importance of the oil and gas industry is more complex than these direct operations. The price of crude oil, natural gas and petroleum products reflect not just fuel prices, but electricity, food, and prices of manufactured goods; thus, job markets, international trade balances, and national gross products. The world energy matrix has more than half of the total primary energy supply fuelled by oil and gas as it is shown in Figure 1 (International Energy Agency 2016).

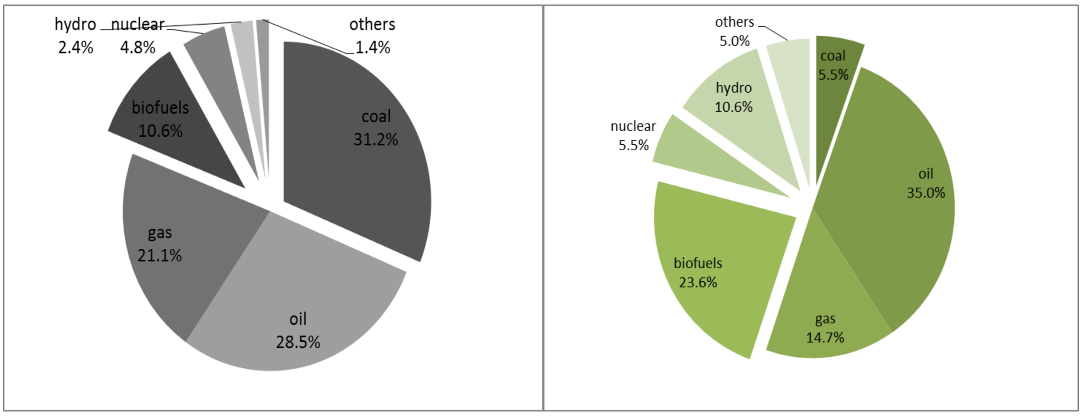

Figure 1. Primary energy supply by fuel: World (left) and Brazil (right).

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According to the International Energy Agency/ IEA, the total fuel supply was 13,699 Mtoe in 2014 representing an increase of 44.5% in respect to the 6,101 Mtoe of 1973. For comparison, the world population increased 55% in the same period (3.9 billion people in 1973 to 7.2 in 2014).

Such dependence on the oil and gas industry has pushed exploration from onshore land (1859, Pennstate) to the offshore sea (1947, Gulf of Mexico 10 miles/ 18 feet deep) into deeper waters (1975, Cognac > 1000 feet and 2010, Perdido ultra-deep > 8,000 feet / 200 miles offshore). This move means an offshore share of 30 % of the total crude oil production in the world today, after a 2% in 1954 and a 20% in 1970 (Manning 2017). Brazil is the 9th petroleum producer and the 6th petroleum consumer. Predictions show their continuous growth as there are few sustainable substitutes for oil products as fuel for trucks and planes and as a feedstock for chemicals industry. Exploration and production of oi and gas in deep and ultra-deep waters became feasible due to heavy research and development developed by major oil companies in the world. And it is still faced with several technological challenges as offshore is advancing to increasingly hostile environments. The complexity of such challenges has moved oil and gas companies close together in agglomerates, e.g. in the Campos Basin there are 1,500 companies in function of about 400 offshore activities (Silvestre & Dalcol 2009).

Together with this offshore sector growth increased the interest on Underwater Welding (UW) as this process is widely used in the construction, installation and repair of offshore structures and shipbuilding. There are known risks involved with UW repair such as hydrogen induced cracking and porosity imposing bigger challenges to the process and materials development related to these specific offshore operations.

2. Offshore industry

Offshore platforms, oil platform/oil rig, are large structures with facilities to drill, extract and/or process oil and gas located under seabed. They are energy and water self-sufficient housing electrical generators, water desalinators and all the necessary equipment to operate and deliver onshore by pipelines or tankers. In offshore drilling, the first step is to move the rig to the drill site and secure it in position. In relatively shallow water, the drill rig will be secured on top of a superstructure whose base sits on or penetrates the sea floor. But in deeper water some type of tethering system must be used to hold the rig in place. A variety of rigs have been designed for this purpose with the size and complexity of the rigs increasing with increase in water depth. Classification of water depths in the oil and gas industry: < 350 m shallow water, < 1500 m deep water, > 1500 ultra-deep water. Offshore platforms are conventionally categorized in two types:

- Bottom supported and vertically moored structures (FP/ fixed platform, CT/ compliant tower, TLP/ tension leg platform, mini-tension leg platform)
- Floating production and subsea systems (SP/ SPAR platform, FPS/ Floating production systems, SS/ Subsea systems, Shuttle tanker, FPSO/Floating Production, Storage and Offloading)

Today there are around 7000 offshore platforms installed worldwide; with the major offshore fields being: (1) Safaniya, Saudi Arabia (> 50 bb, 1.5 mb/day), (2) Upper Zakum (21 bb, 0.5 mb/day), (3) Manif in the Persian Gulf, (4) Kashagan (35 bb) in the Caspian Sea, (5) Lula (6.5bb) in the Santos basin.

From the Design of the offshore structure, safety management should be included during their life cycle operation. Thus, in this specific case, design, safety management includes, additionally to the engineering aspects such as safety factor calculation of the materials components, a system for safety inspections during fabrication, installation and operation of the offshore platforms and pipelines. The safety management of structures is different for different industries depending on the organization as well as regulatory contents. Initially civil engineering was the driving force for structural safety management. Later the aeronautical and nuclear industries also played an important role. However in the last 20-30 years the developments in the offshore industry has had a significant impact on the development of safety approaches. This is partly because the offshore industry plays a key role in the "world's economy". Moreover the oil and gas represent energy with large potential accident consequences. Offshore companies involved in structures or facilities that experience accidents may suffer loss of reputation and damage of public's trust.

3. Brazil offshore

The greatest part of the oil and gas being produced in the world today has origin in underwater reservoirs distant from the coastline. These should be mainly explored up to a maximum of 200 nautical miles (370.4 km) from every country's coast. In Brazil, more than 95% of oil exploration is already located off the coast, with related offshore technologies accelerated after the discovery of pre-salt. Repairs and modifications of steel platforms, tanks and pipelines by underwater welding is already a routine activity in this industry.

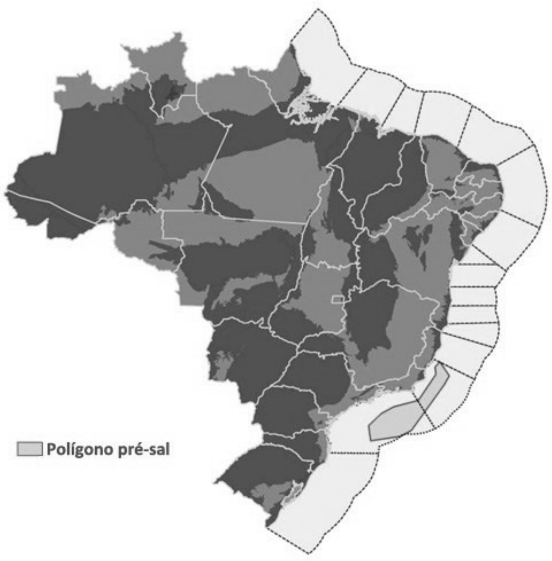

Figure 2. Brazilian territory – the basins and the pre-salt polygon (/"Polígono pré-sal").

Regulation for the exploitation and production of oil and gas in Brazil is called a mixed regulator regime since 2010 through the Law No. 12.351 for the unlicensed areas of the pre-salt polygon and other strategic areas (Brazil 2010). According to this Law, Petrobras will always have a minimum of 30% participation in the composition of operation consortia. For the rest of the territory, about 98% of the sedimentary basins, continues the concession regime established by the Law No. 9.478/ 1997 which allows other companies based in Brazil under Brazilian laws to operate activities from well to wheel (Brazil 2010). Thus, until 1997 Petrobras had the monopoly over the oil and gas in Brazil. This Law also established the National Energy Policy Council/ CNPE to propose new politics for the sector and the Petroleum National Agency (ANP) to regulate and define legislation for the sector. The CNPE decide whether, in a certain area of the pre-salt polygon, it will conduct bids or direct contracting of Petrobras. The areas and date of the bids for distribution, as in the concession regime, will also be defined in a CNPE resolution and be promoted by the ANP. Companies interested in exploring and producing in the pre-salt will participate in this bidding process and will conquer the one that offers the Brazilian State the largest surplus share of oil and natural gas.

3.1. Pre-salt reservoirs

The Brazilian pre-salt reservoirs are estimated to be of 124 miles (/200 km) width per 497 miles (/800 km) length in a depth of more than 22,968 feet (/600 km); comprehending the basins of Santos, Campos and Espirito Santo in the southeast coast of the country. The pre-salt is one of the big attractions of the oil and gas industry in the world as it has imposed a new technological challenge for the offshore oil and gas sector. In a national level, Petrobras experience in deep waters guaranteed an excellent starting point for Brazil. The pre-salt introduced issues for improvement of the methods and processes applied to wells already in production and the well testing systems. As it has already done in the past, Petrobras is working in coordination with services providers, universities, and research institutes.

3.2. Petrobras

Petrobras, Petróleo Brasileiro S.A., is a semi-public Brazilian multinational corporation in the oil and gas exploration, production and distribution activities. It operates through the following segments: Exploration and Production; Refining, Transportation, and Marketing; Distribution; Gas & Power; Biofuel; International; and Corporate. The company was founded on October 3rd of 1953 with headquarters in Rio de Janeiro. Petrobras is the company that operates the largest number of FPSOs (own and chartered) in the world.

Together with the discovery of oil deposits in shallow water on the continental shelf in the 1960s, the first production units installed by Petrobras were the fixed platforms, nailed to the seabed, first in the Brazilian Northeast and later on the Southeast coast. With the advancement of deep-water exploration in the Basin of Campos, in the first half of the 1980s, the company's alternative was the semi-submersible platforms and FPSOs. One of the major advantages of FPSOs is that they exempt the installation of oil drainage infrastructure, since they are equipped with storage systems and the transfer of the produced oil to the coast is done by relief vessels. In addition, because they can be built from the conversion of a pre-existing ship hull, they allow a faster installation of the production unit.

3.3. FPSOs

The advance of the exploration for deep waters, in the middle of the oil crisis, required a quick and economically viable solution to put in production the fields like Marlim and Albacora, the first located at depths exceeding 500 meters. In this horizon of depth it was technically unfeasible to install fixed platforms, nailed to the seabed. Thus, in the midst of an acute crisis of oil supply, which required the newly discovered fields to be rapidly put into production, the solution was to convert large oil tankers with the installation of processing modules on the deck, in production units. With more than 30 years of experience in the use of this type of platform, as already mentioned Petrobras is the company that operates the largest number of FPSOs in the world.

The pioneering experience in this field was the conversion of an oil tanker into a platform ship in 1977. It was the solution found to anticipate the production of the Garoupa field in shallow waters in the Campos Basin with the conversion of the oil tanker Presidente Prudente. The result was a significant saving of time and resources. It was also the first time Petrobras used the FPSO concept, adapted to the Brazilian deepwater scenario. With the good results of this first experience, the company decided to invest more and more in the conversion of existing oil tankers into definitive production systems. The new platform ships were the best strategy for a company whose major part of the production would be in deep and ultra-deep waters. Today, almost all of the oil produced (about 90%) comes from the sea, both in shallow water and deep and ultra-deep, by the various types of production units. Campo de Lula in 2010 was operating with one unit (Angra dos Reis) and jumped in 2016 to six units (Angra dos Reis, Paraty, Itaguai, Mangaratiba, Maricá, Saquarema). Moreover, it is observed an international tendency for the use of floating units in the offshore production and this may place Petrobras in a leading position due to its numerous and long time experience.

3.4. Subsea pipelines

The continental dimensions of Brazil impose a great quantity of terminals and pipelines, which are operated by Transpetro – Petrobras Transporte S/A, ensuring the transport of products between oil and gas fields to refineries and distribution bases. Brazil today has available 14,000 km of oil and gas pipelines within its 47 terminals and 56 tankers for transportation operations. The first gas pipeline started operation in the 1960s, the GASEB in Bahia; then in the 1970s with the discoveries in the Campos basin resulted in the GASVIT (Espirito Santo), GASVOL (Rio de Janeiro) and GASPAL (Sao Paulo). In the 1980s it was constructed the NORDESTAO connecting the gas in the Rio Grande do Norte state to the states of Paraiba and Pernambuco. In the 1990s, the Merluza field in the Santos basin was connected to the refineries of Presidente Bernardes and Capuava by the GASAN pipeline, followed by the GASFOR and GASALP. In 1996 the pipeline GASBEL connected the units in the Campos basin to the Minas Gerais state. Finally, in 2000s, the GASBOL connected Bolivia units all the way by 3,150 km to the Rio Grande do Sul state (Renno 2013).

Regarding inspection of these pipelines, a part from the conventional remotely operated vehicles (ROVs) inspection, the pigging technology is used to inspect for corrosion, cracking or buckling defects both internally and externally. It must be taken into account that repair of these in-service pipelines by UW is challenging due to risks of hydrogen induced cracking and high porosity of weld beads. In relation to the material, high strength steel is developed for large pipelines to increase operational safety, facilitate monitoring and repairs, and to reduce costs of new pipelines assembling. Moreover, the research and development is majorly conducted by CTPetro and CENPES (Passos 2013).

4. Underwater Welding

Underwater welding (UW) began during World War I, when the British Navy used it to make temporary repairs on battle ships. The introduction of covered electrodes made it possible wet underwater weld with similar quality to process made in air. Originally it was restricted to salvage operations and emergency repair work, limited to depths of not over 10 m, then it evolved as a method of repair and construction of engineered structures in several sectors involving submerged applications such as nuclear energy and water-sewage systems. UW is being used for construction, repair and rehabilitation of offshore structures (e.g. oil and gas platforms, piers and harbour systems, etc.).

The research and technological development related to UW operations is promoted by the oil and gas industry, thus, in Brazil these are majorly financed by Petrobras. Since the beginning of 1970s Petrobras have initiated the development of UW techniques. Due to the installation of the first fixed structures made of structural steels: Garoupa RJS-9A at 120 m in 1974, Enchova EN1-RJS at 124 m in 1977, Bonito RJS-38 at 189 m in 1979. In the beginning of the 1990s, Petrobras moved to deeper reservoirs with Marlim MRL-9 at 781 m (in 1992) and Marlim MRL-4 at 1027m (in 1994) still by using semi-fixed platforms. Then finally in the late 1990s, the FPSOs were introduced with Marlim Sul MLS-3 at 1,709 m (in 1997) and Roncador RJS-436 at 1,877 m (in 1999). Already in 1997, Petrobras developed a specific standard for the welding operations performed underwater - the N2036 Subaquatic Welding (PETROBRAS 2011). As it is stated in this standard, the weld quality required must be previously established according to the intended application of the welding such as anode fixation, structural repair, pipeline repair, and operational and safety aspects. The acceptance standards of this Petrobras standard are according to the different weld classes (A, B and O) such as the ones defined by the American AWS D 3.6M standard (American Welding Society 2010).

4.1. Materials and properties

From the literature analysed, there are mainly studies related to UW process techniques using structural steel and then secondly with aluminium alloy materials. However, there are other alternative materials being investigated and being employed in the offshore industry such as fibre-reinforced composites. The UW operations are mostly performed on structural steels (in Brazil, the ASTM A-36 / SAE1010/20) as it was extensively used in the construction and repair of marine structures and underwater pipelines. However, the fast cooling rates of underwater welding result in the formation of constituents such as martensite and bainita leading to a high-strength, brittle material with much higher susceptibility to hydrogen-induced cracking. These materials transformation are responsible as well for a bead shaped weld more spread out and less penetrating than air welds.

Stainless steels for marine applications were specially designed to be very resistant to corrosion with high strength up to 350 MPa (50 Ksi) and hardness up to 400 Vickers. Major applications and grades are: Coastal handrails, housings for equipment, ladders, lamp posts, Deck components for boats and ships (1.4401/ SAE 316, 1.4404 / SAE316L, 1.4552/ 17/4 PH), Boat propeller shafts (1.3964/ Nitronic 50), Submerged pipelines and grills, risers for platforms, heat exchangers for ships and coastal power plants, equipment attached to hulls of boats and ships, pumps, winches, holding and storage vessels (1.4547/ASTM S31254, 1.4529) (Gerwick 2007).

Aluminium alloys, especially marine-grade, have excellent combination of high strength combined with superior corrosion resistance plus weldability makes them ideal for applications on marine transportation and offshore components. Similar to welding other aluminium alloys, welding marine-grade aluminium alloys can be challenging because of their high thermal conductivity and low melting temperature. Although some conventional welding techniques could be used to weld aluminium alloys, some of the applications are very difficult and costly as the alloys need to be welded underwater (Kishta & Darras 2016). Examples of applications of some Al alloys are: Hull material (5083, 5383, 6061, 6063), Superstructure (5083, 5456), Structure beams (6061, 6063), Pressure vessels (5083, 5086, 6061, 6063), Offshore stations and tanks (5083, 5456), Pipelines (6061, 6063, 6070) (Kaufman 2000).

Overall, steels (especially low carbon steel) will be the dominant materials due to its advantage of resources abundance, solid technological experience linked to a well-established and secure supply chain. However, there is an ever increasing challenge for advanced materials for deep water drilling, oil reservoir rich in CO_2 and sulphur, large capacity platforms, and ocean vessels. Moreover, it is gradually occurring the introduction of fibre-reinforced composites as potential substitutes of underwater welding for the repair of steel pipelines (Shamsuddoha et al. 2013).

Regarding the consumable materials, electrodes commercially available also for UW applications can be of: ferritic types (e.g. E7014 and E6013), austenitic stainless steels types (e.g. E309-16 and E310-10), electrodes (e.g. E7018 and E7016) and nickel base alloy coated electrodes (Rowe & Liu 2001). Large manufacturers have being replacing electrodes by solid and tubular continuous wires, but coated electrodes are still widely applied due to: simplicity, durability, and low cost of the equipment required; possibility of being used in open and closed locations; relatively ease of finding welders with the required skill; wide range of consumables for most applications as a function of the quick setup; availability in small units at relatively low cost (Łabanowski 2011). In Brazil, there is specific research and development being conducted to improve electrodes performance for the wet UW applications by several research institutions and it was obtained significant advances. From 2007 to 2012 the collaborative research projects coordinated by Petrobras resulted in the development of an oxy-rutile electrode entitled WW70 with mechanical properties of AWS E70XX class (Marinho et al. 2014).

In respect to the material properties is commonly stated that the most deleterious defect is the weld porosity. Its influence in the underwater welds is assumed to be similar to sintered steels with porosity playing a major role in the decrease of tensile strength (up to 20%) and toughness (up to 50%). A recent study has shown that porosity also decreases the fatigue crack resistance of repaired materials by UW in 10 and 60 meters depth (Arias & Bracarense 2015). Mechanical properties of welded joints are critical to the system integrity and damage or complete fracture is mainly due to: corrosion, cracks failure, collision accidents, design and process errors, fatigue, exceeding life cycle. Summing to the different conditions of environment and accessibility of this specific welding process, special quality requirements and inspection procedures were established for the underwater welds. In the latest AWS D 3.6M: 2010 norm there are specified three weld classes: A, B, and O. As in other welding processes, the weld to be classified in a certain class, it must meet all the criteria and requirements of the specific norm.

Moreover, phenomena related to metal transfer are still being investigated for better understanding of the arc stability, molten pool, weld formation and quality. It was very recently that clear metal transfer images of UW with a self-shielded flux-cored wire (TiO_2-CaF_2-CaO-SiO_2 slag system, 1.6 mm diameter) were reported as obtained by X-ray transmission method with the monitoring of droplet transfer mode, size and frequency (Guo et al. 2015)

4.2. Process techniques

There are five basic methods of underwater welding currently in use, according to AWS D36 2010: In a pressure vessel (dry welding at one atmosphere), at ambient pressure in a large chamber (dry welding in a habitat), at ambient pressure in a simple open-bottomed dry chamber (dry chamber welding), in a small and transparent gas filled enclosure (dry spot welding), and at ambient pressure with the welder in the water (wet welding) (AWS 2010). Thus, more generally, the present underwater welding techniques can be divided according to the process environment into: dry welding (UDW) and underwater wet welding (UWW).

Regarding depths, UDW will be used for deep depths from 30 to 100 m or reaching 1000 m for lab tests; while the UWW comprehend operations usually about 10 m or reaching 50 m with robot assisted. The most important process parameter is the current as for most of UW it requires a higher current for the same arc voltage in order to achieve the same heat input of air welding. Thus, welding in shallow depth is less critical technically and economically than in deeper depth as it mainly differ on process technique (from Wet to Dry conditions). The main result of an unstable arc is the increase of porosity affecting the weld soundness and consequently the component properties.

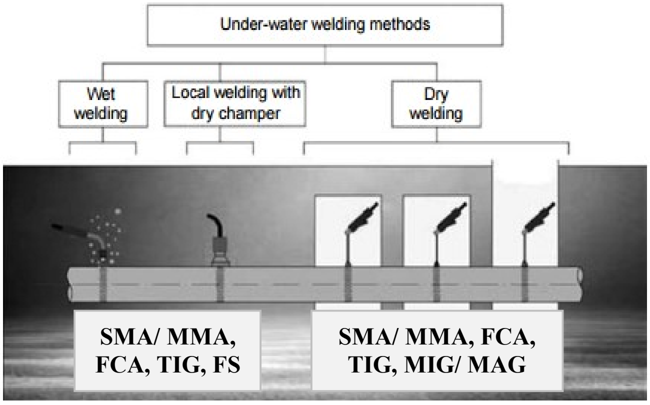

Figure 3. Classification of underwater welding and most common techniques – adapted of (Layus et al. 2013).

The most commonly used commercially UW processes are Shielded Metal Arc Welding (SMAW) and Flux Cored Arc Welding (FCAW). However, Friction-Stir Welding (FSW) and Laser Beam Welding (LBW) have been extensively investigated and have been tested as potential UW alternatives.

SMAW is a very known and established technique where trained divers perform the welding with coated electrodes. The limited length of the coated electrode makes automation of this particular process very difficult, independent of welding medium. On the other hand, FCAW even if requires much longer time it is a promising technique to be automated for underwater welding. A part from the automation, optimization of weld bead geometry is another important aspect that is being approached by several statistical techniques such as regression analysis, response surface methodology, Taguchi method, and more recently artificial neural network, genetic algorithm, and sensitivity analysis (Pal & Pal 2011).

FSW and LBW are relatively novel welding techniques that show high potential for underwater welding applications. Although the base metal does not melt during FSW process, improper thermal cycles still can cause reduction of mechanical properties of the joints. Thus, there is an ever increase focus on controlling the heat input of the underwater FSW process (Kumar et al. 2014). In the same way, LBW results in precise heat input and diffusion controls of the weld related material (Anand & Khajuria 2013). Unlike other welding techniques, FSW and LBW can be performed on samples submerged in water using the same procedure as in air welding.

Other recent review papers on the state of the art of UW technology were published with brief descriptions of different aspects of these main process techniques (Alajmi 2016, Alam et al. 2016, Chandra Joshi et al. 2016, Jyoti Group Of Instititutions Shambhu Kalan et al. 2015, Majumdar 2006, Omajene et al. 2014). From the overall manuscripts indexed (since 1969), Brazil is in the 4th place with 41 documents after China (1st, 170), Japan (2nd, 64), United States (3rd, 57); regarding quantity of documents by affiliation UFMG (Universidade Federal de Minas Gerais) and by author A. Q. Bracarense both appear in the third place. From this literature, the available articles were analysed and a summary is given in Table 1; as it can be observed most of the published works conducted in Brazil during the last ten years have investigated using similar welding conditions (SMAW) and materials (ASTM A-36, E6013) for a more detailed understating of main aspects related to the weld final quality regarding characteristics such as porosity, diffusible hydrogen, and others correlating to water depth and materials composition.

Table 1. Chronological list of the studies related to the UW process conducted by the Brazilian research groups

Process and parameters Technique | Current (A) | Voltage (V) | Welding velocity (mm/s)	Materials and operation Base Metal (thickness, length, mm) | Electrode (diameter, mm) | Water Depth (m)	Ref. (Author Year)
FSW	ISO 3183 X80M (12) | 300 rpm spindle, 30 KN axial | 100 mm/min	(Hoyos et al. 2016)
SMAW | 158-162 | 30-36 | 300-500 mm/min	A 572-50 (12.7) | E7014 (3, 350) | 10-40	(López et al. 2016)
SMAW | NS | NS | NS	Low carbon steel | Rutile-coated (3.25) | 0.5, 10, 20	(Silva et al. 2015)
SMAW | 160-170 | 75 | 3.2 , 3.5 mm/s	NS | E6013 (3.25, 350) | Air, 10, 60	(Arias & Bracarense 2015)
SMAW| 160, 190 | 28-32 | Gravity	ASTM A36 (20) E6013 (2.4, 3.2, 650) | 50, 70, 100	(Terán et al. 2014)
SMAW 150-170 | NS | Gravity	ASTM A-36 (16) | Oxy-rutile EXX 2wt.% Ni, 0-0.4wt.%Mo (3.25, 35) | 10	(Silva et al. 2013)
SMAW | 160 | 29-37, 29-32, 21-29 | 4.1, 2.8, 2.5	ASTM 36 (8) | E6013 , E7024, E7018 (3.25) | 0.5 m	(Oliveira et al. 2013)
SMAW | 230, 290 | NS | Gravity	A 572-50 (17) | E6013 (5) | 0.5, 50	(González et al. 2012)
SMAW | 170 | 19-31 | Gravity	ASTM A-36 (12.7) | E6013 (3.25) | 0.3, 10, 20 ,30	(da Silva et al. 2012)
SMAW | 150 | 22-37 | Gravity	ASTM A-36 (16) | Oxy-A, Rutile-B-E (3.25) | 0.5	(Bracarense et al. 2010)
SMAW | 210 | 25 | Gravity	AISI 1010, C2(0.24%C), C7(0.7%C) (4.765) | E6013, E2(0.001%C), E6(0.062%C) (4.0) | 50	(Andrade et al. 2010)
SMAW | 260, 290 | 22, 29 | 3.4, 4.3	ASTM A36 (10) | E6013 (4, 350) | 50, 100	(Puchol et al. 2009)
SMAW | 260, 280 | NS | 3.0- 5.0	ASTM A-36 (12.7) | E6013, E7024 (5) | 50, 100	(Pessoa et al. 2006)

*NS: Not Specified.

4.3. Research institutions

Regarding the research related to UW technology being conducted in Brazil, there are several institutions working in individual or collaborative projects, mostly financed by Petrobras.

FBTS – Brazilian Foundation of Welding Technology (/Fundação Brasileira de Tecnologia da Soldagem: http://www.fbts.org.br), in the city of Rio de Janeiro since 1982, has the aim of supporting the demand created by Petrobras, regarding welding technology issues due to the implementation of the first platforms in the Campos basin, located in the state of Rio de Janeiro. It is running in cooperation with the following companies and research institutions: Petrobras, ABEMI, ABDIB, FIRJAN (CIRJ/SENAI), ABENDI, SINAVAL and LIGHT. The FBTS facilities are composed by the following laboratories: Welding process, Visual inspection, Weld dimensional, Non-destructive tests and Metallographic analysis. There is also an informatics structure that gives support to online courses and to the students of other courses. Regular courses offered at the FBTS: post-graduation in Welding engineering; Wlding inspector level 1, on-site or partially; Complementation for Welding inspector level 2; Equipment inspector; Fabrication inspector; Pipelines inspector, construction and mounting; and in-demand developed courses. It is also responsible for the Centre of Inspectors Qualification of Welding and Pipelines / Centro de Qualificação para Inspetores de Soldagem e Dutos Terrestres and by the application of qualification and certification for the National System of Qualification and Certification / Sistema Nacional de Qualificação e Certificação – SNQC.

Centre of Welding Technology SENAI – **National Services for Industrial Learning** (/Centro de Tecnologia Solda SENAI/Serviço Nacional de Aprendizagem Industrial: http://www.cursosenairio.com.br/) Materials technology facilities: Scanning Electron Microscope, Optical emission spectroscope, Hardness test (Vickers, Brinell, Rockwell), Microhardness (Vickers, Knoop), Thermal-mechanics analysis by physical simulation, Tests of tension-stress, bending, impact, Nick-break, Fracture and Adhesion. Non-destructive inspection by: Ultrasound (Phased Array and ToFD), ACFM, Finite Elements simulation (CIVA, SYSWELD, ANSYS, SOLID WORKS, ABAQUS), Fatigue and CTOD tests, Visual inspection by Borescope, Thermography, Radiography (conventional and computerized). Welding technology by: Tubular wire, Submerse arc, Plasma cutting, Coated electrode, TIG / Orbital TIG / Plasma TIG, MIG/ MAG, Thermal Spray, Robotic welding (GMAW/FCAW) ,Hybrid laser (16 KW), High speed camera. Partners: FBTS, ABENDE (Associação Brasileira de Ensaios Não Destrutivos e Inspeção), ABS (Associação Brasileira de Soldagem), AWS, ABRAMAN (Associação Brasileira de Manutenção), INT (Instituto Nacional de Tecnologia).

UFMG – Federal University of Minas Gerais by the LRSS – Laboratory of Robotics, Welding and Simulation (/Laboratório de Robótica, Soldagem e Simulação: http://www.demec.ufmg.br/lrss/) created a more than 70 years, this unit is specialized in welding technology and robotics. LRSS has as main aim: technical-scientific improvement of the professional in the automation and welding process areas, development and implementation of new Technologies together with supporting services in robotics, welding and simulation. Research facilities: welding equipment LINCOLN Power Wave 450, welding equipment BAMBOZZI TIG150 BAMBINA AC/DC, Scanning Electron Microscope JEOL JSM-5310 within the magnification up to 200.000x, mechanized welding system controlled stepper motor by Cyberresearch, camera with high velocity system. Research development: services provision and projects development in cooperation with companies related to welding in general. Main researchers: Alexandre Queiroz Bracarense, Paulo José Modenesi, Paulo Villani Marques.

UFRJ - Federal University of Rio de Janeiro by the LNDC – Laboratory of Non-destructive Tests, Corrosion, and Welding (/Laboratório de Ensaios Não Destrutivos, Corrosão e Soldagem: http://www.metalmat.ufrj.br/lndc) which promotes the main research lines: Evaluation of welding of structural steels resistant to corrosion; Evaluation of composite structures and steels as heat exchangers for magnetic analysis; Evaluation of the fatigue properties of rigid and flexible risers, Inspection study of corrosion defects in oil storage tanks by acoustic emission; Corrosion by multiphase flux and Corrosion under stress; Development of mechanical equipment for the submarine analysis of corrosion in ships hulls by non-destructive tests; Analysis of Corrosion-Fatigue tests under high stress and of anti-corrosive protective systems; Fracture analysis of metallic materials and welds; Welding of advanced stainless steels and Microstructural characterization correlated to mechanical properties and corrosion.

UFRGS – Federal University of Rio Grande do Sul by the LS&TC – Laboratory of Welding and related techniques (/Laboratório de Soldagem & Técnicas Conexas, da: http://www.ufrgs.br/lstc/), this laboratory is considered by the national welding community as one of the most well-equipped, with facilities such as an workshop, metallography lab, mechanical properties tests. The LS&TC keeps permanently exchange with the industrial sector using welding as primary process, with its research aim on promoting the development welding technology in all aspects.

FURG – Federal University of Rio Grande by the LAPES – Laboratory of Research in Welding Engineering (/Laboratório de Pesquisa em Engenharia da Soldagem http://www.lapes.furg.br/index.php) created in 2013 with the aim of develop and improve the techniques and equipment, in addition to the study of the physical metallurgy of the arc, corrosion, defects and other phenomena related to the welding process. Tthe LAPES research group uses experimental techniques of manufacturing automation such as robotics, electronically controlled welding sources, numerical analyses, and data treatment for the solution of the themal-structural problems using finite elements.

UFSC – Federal University of Santa Catarina by the LABSOLDA – Institute of Welding and Mechatronics (/Instittuto de Soldagem e Mecatrônica: http://labsolda.ufsc.br/), assembled in 1974, it has been developing research on welding technology and its automation. From the projects and collaboration in 1992 it was initiated two companies: IMC-Soldagem manufacturer of welding source units and SPS-Soldagem for the production of automatized welding systems. Process technologies: robots MOTOMAN UP6, MOTOMAN HP20D integrated to CMT 3200, and MOTOMAN SIA10D integrated to STT 455M; Powder Plasma welding PTA-P 250; automatize welding unit PTA-P; MIG/MAG, TIG and Plasma; Orbital TIG; Gases mixers WITT; Gas analyser Thermco; Electronic multi-process welding source units; portable data treatment SAP; high-speed camera and data acquisition; Digital ultrasound phased array inspection; and X-ray equipment. Research lines: Welding automation - Mechanization and Sensing, Instrumentation and peripherals for welding and its automation; Non-destructive testing; Additive Manufacturing; Advanced Processes for Aluminium and Special Alloys Welding; Hybrid Welding Processes; Coating and Repair via Welding Processes; Laser Welding; Orbital Welding; Plasma Welding and PTA-P; Underwater Welding; Stud welding; MIG / MAG Process; TIG Process. Since 1995, LABSOLDA has been developing research related to UW, starting with the project entitled "Development of Tubular Electrode Welding for Application in Submarine Environments"; which resulted in a dedicated welding source unit for UW, many specialized conference papers and a master dissertation.

5. Conclusions

Overall, offshore structures, pipelines and floating units will continue to be constructed and repaired to attend the increasing demand of oil and gas located under deep waters. Thus, underwater welding as the most advantageous technique regarding operational costs will continue to be a significant importance especially for the in-loco construction and repairing of these naval structures. The use of remotely controlled vehicles is a favoured alternative in human limiting operations. However, the tendency indicates that in the splash zone inspection, maintenance and repair tasks will be undertaken by divers due to the difficulties of operating vehicles in high currents or wave action. Still some of the critical issues associated with UW are: depth limitations for human divers and the welding defects and failures induced by hydrogen cracking, porosity and lack of fusion. The depth limitation could be overcome with the automation of the welding process, while the defects are more critical as it results in poor mechanical properties which are just partially solved up-to-date. Thus, the UW applications, especially for diverless deep-water conditions, is limited not by the welding process or the material properties, but by the development of remotely operable technologies.

Lastly, exploiting the under seabed is the next frontier for the mining and energy industry. Offshore mining will advance together with technological development of ultra-deep water oil and gas industry. Seafloor deposits contain high concentrations of copper, zinc, gold, silver and other trace metals. To develop ocean mining, and methane exploitation, the technology developed for deep water oil and gas exploitation is being used; including robotic marine undersea technology; piping systems and risers will serve as conduits to the ocean surface.

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