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ADHESIVES IN THE OIL INDUSTRY

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Abstract. *In the oil and gas industry, welded or bolted joints are widely used in the construction of structures and platforms. In some cases during the construction of a platform, it is necessary to perform a repair or an installation of a new equipment or additional supports on the deck and the weld can cause, for example, damage to the paint of an oil storage tank located below the deck of the platform. This causes many delays in the construction and requires complex rework operations especially in confined spaces. With the advancement of polymers, powerful adhesives are being developed and in some situations may be a good application in the place of welded joints. The adhesives have already been widely used in the automotive, aeronautics, aerospace industries, dentistry and medicine. In this work, there is a brief explanation of the adhesives type, adhesion mechanisms and applications used in the oil and gas industry. This work is intended to explain the use of adhesives and has the intention of describing standards, possible applications, experience and attentions to a specific adhesive application. Rules of the Classification Societies shall be followed when there is a float installation and the safety for people and installations must always be taken into consideration.*

Keywords: *Adhesion, Adhesives, Joints, Offshore, Onshore*

1. INTRODUCTION

Adhesives have been shown to be an alternative for bonding or repairing instead of welded structures. This favors the adhesives application because it is not necessary for intertie confined areas or tanks when welding has been used. Nowadays in the Oil and Gas industry, there are many possible applications such as adhesion of commings (oil leaks containment basins on the deck of platform), platform side repairs (FPSO – Float, Production, Storage and Offloading), saddles bonded in metal pipes or FRP (Fiber Reinforced Plastic) pipes, bonded unions of FRP pipes.

When welding happens in the metallic materials, welders have their qualification controlled, updated and inspected. The use of adhesives also requires that the applicators have a rigorous qualification, which is still in development for specific works. For a right dimensioning of the adequate adhesive it is necessary to know some features such as mechanical properties, temperature limits of applications, surface preparation required, creep behavior, fatigue resistance, chemical and environments resistance and fire resistance. The adhesives and composites manufacturers have this purpose, and are helping a lot in order to ensure the quality for the final product performance and a safe operation. Besides that, float units are under the Classification Societies (BV, DNV, ABS and Lloyds Register) requirements, rules and approvals, and they need sometimes to qualify a bonded joint for a specific application.

The durability of adhesives are very important for offshore applications, because the costs for maintenance and operations in the platform are very high. Van Lancker, *et al.*, 2016 presented a work with application of several adhesives type and different manufactures showing ageing and its influence in the strength of the adhesives.

Souza *et al.*, 2018, describes an experimental study about the durability of a cold curing structural epoxy adhesive exposed to different moisture and outdoor ageing environments, typical of civil engineering applications, for up to two years: water and salt water immersion at 20°C and 40°C, continuous condensation at 40°C, and outdoor ageing in a mild Mediterranean climate. After specific exposure periods, changes in the following physical properties and mechanical behavior of the adhesive were assessed: media diffusion, through water uptake (in moisture environments); viscoelastic behavior, through dynamic mechanical analyses (DMA); and flexural and in plane shear behavior. Despite this work was directed to civil engineering applications, the results have showed limitation for epoxy adhesive under the environmental conditions.

Galvez *et al.*, 2019 developed a work dealing with the use of reinforcing materials in steel structures with the combination of composites and adhesives that are capable of bringing great improvements to steel structures. In that work it was proposed a steel-CFRP (carbon fiber reinforced polymer) adhesive joint, trying to combine the good properties of both materials. Two structural polyurethane adhesives were selected, one conventional and another one hybrid, to develop the joint due to the good properties of this material against external environmental agents and the high loads that are capable of resisting. The work also verified the suitability of this type of joints for structural applications in aggressive environments. An important contribution was the reliability studies using a simplified model of the Weibull distribution, obtaining the distribution of failures of the joints. In that work it was used microscopy techniques (Scanning Electron Microscope and optical microscope) to evaluate the failures of the studied specimens. The reliability of the joints was also verified under extreme aggressive conditions. Even having different behavior in the adhesives, both of them are able to maintain adequate strength after the degradation process, according to Galvez *et al.*, 2019. An application at PETROBRAS with CFRP and adhesives will be shown further.

For structures with hang-bonded supports, it is important to verify the adhesive creep behavior, mainly in offshore installations due to environmental conditions variations and the ship movement. Miravalles, 2007 has showed a numerical and experimental investigation of uniaxial tensile creep tests, where two epoxy adhesives were tested at different stress levels. Experimental data showed that the adhesives reinforced with carbon fibers experiment less creep strains than the unreinforced adhesives.

Silva, *et al.*, 2018 in the Oil Industry chapter present methodologies, standards and qualification for repair using epoxies resins and carbon fibers for use in offshore units. This reference describe also, besides a large amount of applications, the world of adhesives.

Arouche *et al.*, 2019, developed investigations about crack in adhesives. In that work, it was analyzed the mixed-mode fracture behavior of a bi-material adhesively bonded joint. It is being developed a new strain-based criterion for the design of the Mixed-Mode Bending (MMB) bi-material specimen. A new analytical partitioning method based on the 'global method' was proposed and tested on a composite-to-metal bonded joint and compared with a finite element model using the Virtual Crack Closure Technique (VCCT). The results show that the proposed strain-based design methodology in MMB test for bi-material joints can be success fully used. The fracture mode partitioning was accurately predicted by the analytical method. However, the absolute values of the strain energy release rate (SERR) predicted by the analytical method are only accurate if the shear deformation in the test is not significant.

2. ADHESIVES TYPES

There are reactive adhesives (Epoxy, Acrylic, and Urethane) and non-reactive adhesives (PVA, Hot Glue and Contact Adhesive are examples). The reactive adhesives bond through a chemical reaction by a simple mixing of two parts, it transforms into a thermoset polymer via a cross-linking process, and they are used for structurally bond. Non-reactive adhesives bond through a physical change and often are used as non-structurally. The one part non-reactive adhesive is a pre-mixed two part adhesive, but the reaction needs UV light, heat, moisture or solvent evaporation. Reactive adhesives such as Epoxy and Acrylic adhesives are a good candidate for joining parts in the oil and gas industry, because each one has a property suitable for a particular application. Some experiments are being developed together with manufacturers but detailed results are in confidential reports.

Table 1 shows advantages and disadvantages for different adhesive family: Epoxy, Acrylic and Urethanes.

Table 1. Adhesive family features.

Features	**Adhesives Family**		
	Epoxy	**Acrylic**	**Urethanes**
Advantages	Better resistance to highs temperatures, weather, solvents and good mechanical strength	Less sensitive to surface preparation	Good impact strenth
		Shorter cure time	More Flexibility
	Large variety of products	Good adhesion on oily metal surface and same plastics (LSE - Low Surface Energy)	
Disadvantages	Dependence of surface preparation	Shorter life time of nozzle applicator	Dependence of surface preparation
	Long cure time	Less resistance to high temperatures and severe weather conditions	Less shear strength when compared with epoxies and acrylics

Table 2 shown some adhesives typical properties for Epoxy, Acrylic and Urethanes.

Table 2. Typical tensile strength and strain properties for adhesives.

Adhesive	Tensile Strength (MPa)	Elongation at Break (%)
Epoxy (rigid)	34-55	3-10
Epoxy (flexible)	4-28	30-80
Acrylic	20-28	2-30
Acrylic (LSE)	10-14	20-30
Urethane (rigid)	20-28	10-50
Urethane (flexible)	7-10	50-220

Table 3 presents typical temperature applications limits for different type of adhesives and manufacturers. This property is very important because in the offshore platforms, temperatures of operations can be significantly high and the strength of adhesive can be compromised.

Table 3. Typical temperatures ranges for different adhesives.

Adhesive	Temperature range (ºC)
Epoxy	120-180
Acrylic	80-90
Urethane	100-120

For adhesive characterization, a group of standards shall be employ. Table 4 describes main tests for an adhesive and the related standard.

Table 4. Typical list of tests and applied standards.

Test type	**Standard**
Shear strength	ASTM D 1002
Cleavage	ASTM D 3433
Impact strength	ASTM D 950
Tensile strength	ASTM D 638
Thermal expansion coefficient	ASTM D 696
Glass transition temperature	ASTM E 1640
Weather resistance	ISSO 11346
Shear strength after weather resistance	ASTM D 1002
Salt spray (5%) @ 35ºC	ASTM B 117/ASTM 1002
UV resistance	ASTM D 904

3. ADHESION MECHANISMS

The mechanical theory explains that the phenomenon of adhesion is directly linked to the porosity and surface roughness of the substrate with the degree of adhesion that can be obtained. Any type of material, if it is observed at the microscopic level, has a surface composed of valleys and ridges, the surface topography allows the adhesive to penetrate and fill the valleys, resulting in anchorage areas between the adhesive and the substrate.

Apart from the roughness and porosity of the substrate surface, in order to generate adhesion anchor points, it is necessary that the adhesive has a good filling power, the adhesive can penetrate into the valleys and pores of the substrate surface, the adhesive filling power is directly related to its viscosity.

Mechanical adhesion theory does not take into account for the incompatibility that may exist between the adhesive and the substrate, it only takes into account the topography of the substrate and adhesive filling power, and so this theory cannot explain the adhesion between surfaces with low roughness or smooth, nor the lack of adhesion between rough substrates incompatible with adhesive.

3.1 Type of joints stress

When adhesive is applied, it is necessary to know what type of stress the joint is submitted, as shown in the Figure 1. That way the joint can be well dimensioned to withstand the actual forces.

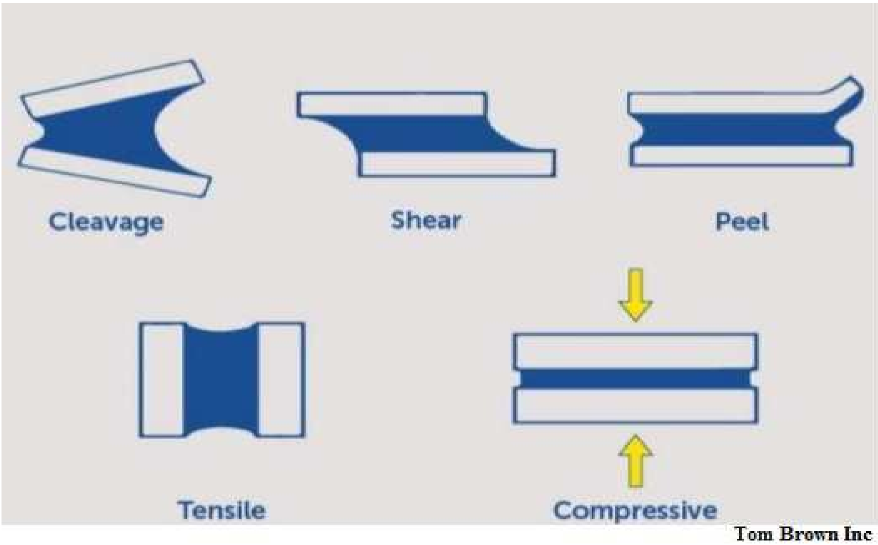

Figure 1. Type of joint stress.

In the offshore applications, the platform movement shall be considered and the type of stress must be identified. The bonding joints shall provide an area of sufficient adhesive surface to meet the stresses of application and articulations may need to be redesigned to provide an area of sufficient surface area for the bonding process. The thickness of an adhesive layer is also an important parameter. If a thick layer of adhesive is applied, the resistance decreases, because the cohesion force is reduced. The adhesive thickness application shall be specified by the manufacturer (typically 0,1mm to 0,3mm for tensile and shear loads and 0,5mm to 1,0mm for cleavage and peel loads) and shall be applied to the entire surface of the surface, in order to avoid crevices that favor the salt-water penetration and metal corrosion as result.

4. TYPE OF ADHESION BOND FAILURES

The performance of adhesive bonded components and repairs in the industry has varied significantly, resulting in a perception that adhesive bonding may not be reliable. Davis and Bond, 2010, suggest that adhesive bond failures require more rigorous examination to accurately assess the causes of these failures as in recent history they have not received the same rigorous investigative scrutiny usually associated with fracture of metallic or mechanically fastened structures. Current poor understanding of adhesive bond failures in some areas of the industry has resulted in some defects being attributed to causes, which, under closer investigation, are shown to be totally unrelated to the true cause of the failure. According to Davis and Bond, 2010, in most cases failures are directly related to processes used for initial production of the bond and are unrelated to the service loads. The authors recommend that adhesive bond failures must be treated in the same rigorous manner as applied to metallic failures to ensure that the technology is applied correctly by the use of proper design, certification and production methodologies. Figure 2, shown adhesives failure types.

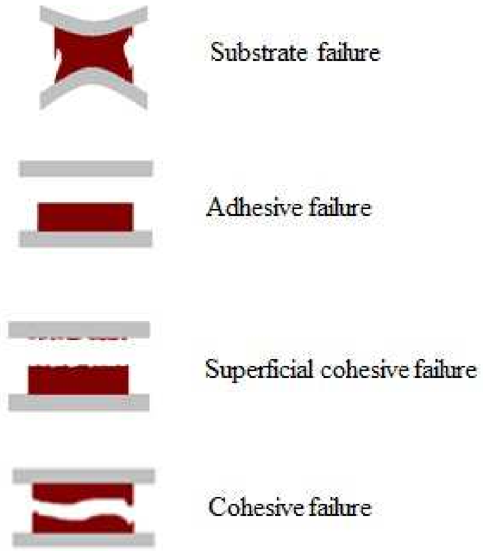

Figure 2. Types of adhesives failures

5. APLLICATIONS

The aim of this paper is to show that adhesives have a high potential of application. In this section it is present some of the successful applications.

Figure 3 shows the side of a FPSO that had a corrosion on the external metal surface. The corroded section was reinforced with a layer of carbon fiber and epoxy resin. The surface of the metal was treated with blasting and then, the carbon fiber and the epoxy adhesive were applied. A scaffold was built on the side of the FPSO with air-conditioned environment for curing the resin and insulation from the saline atmosphere. The FPSO needed to be ballasted, because the repair was extended below the water line. This operation prevented the vessel to stop its operation and transfer to a shipyard. Studies in fatigue and monitoring in the repair due to the ship's movement showed that the repair has infinite life. The thickness of adhesive and carbon fibers were calculated in order to recompose the resistance. The last picture shows workers inside the scaffolds applying adhesives. This repair was qualified and certified by DNV.

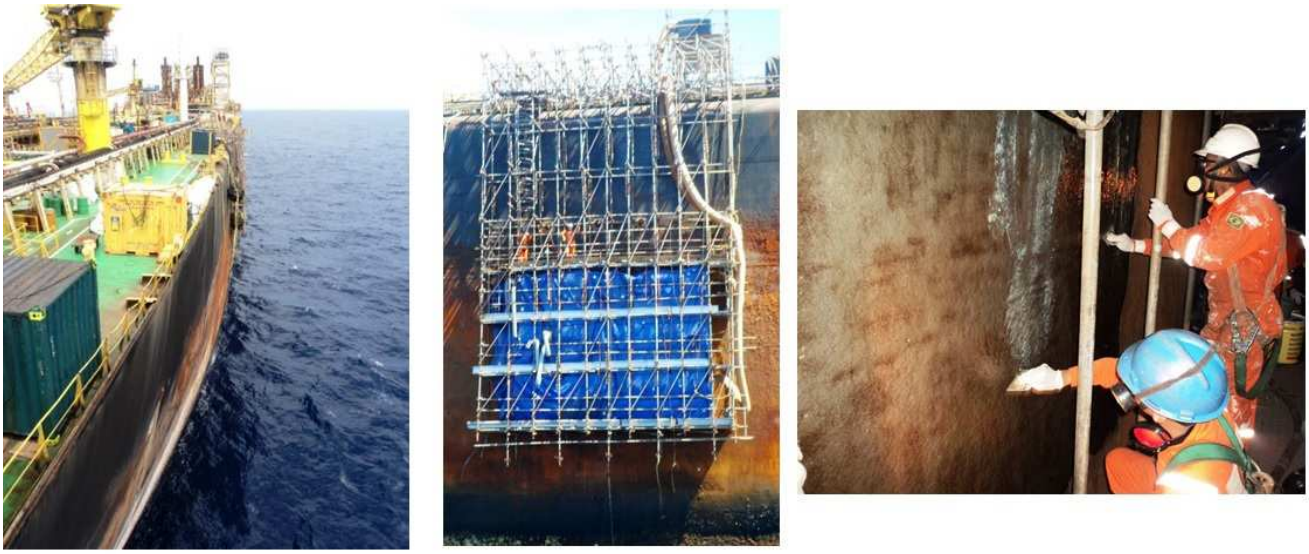

Figure 3. A FPSO repair with carbon fiber and epoxy resin.

Figure 4 shows the repair of an inner tank of a platform. Similar to the FPSO repair shown in Figure 3, the corroded metal part was blast treated and a layer of epoxy resin and fiberglass (FRP) was used to recover the resistant metal thickness.

Figure 4. Repair with fiberglass and epoxy resin inside a tank of platform.

Another application of adhesives is the use of fiberglass saddles in metal tubes, shown in Figure 5. These saddles are applied after the installation of the pipes and are located between the pipe and the supports. This application is very good, because it avoids welding and misalignment between the supports of the pipe in the supports. However, attention should be paid to the application of the adhesive, to avoid crevices that can occur with water accumulation and consequent corrosion.

Figure 5. Saddles of FRP and adhesive applied in pipes.

In offshore units, the saline atmosphere is very aggressive. In addition, pipes conducting corrosive fluids like seawater. The Figure 6 shows another application of fiberglass epoxy resin repair in carbon steel pipes. In Figure 6 a repair test is shown for qualification of the application, where the pipe is pressurized with water until strength limit of the repair. Figure 6 also shows the possible failure modes that can happen in repair.


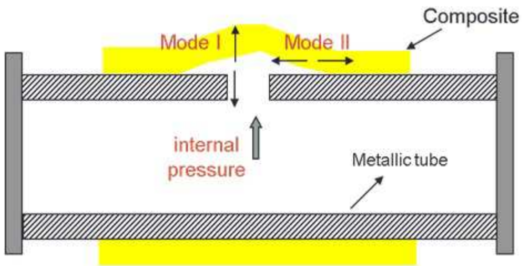

Figure 6. Repair with FRP and epoxy resin.

6. CONCLUSIONS

The use of adhesive joints shall be treated in the same rigorous investigative manner as it is applied to metallic joint (as welded metalic joints). If a correct adhesive specification, adequate surface treatment are applied, limits of temperatures and environment conditions are observed, adhesive joints are a good way for constructions of bonded structures. By identifying the type of joint failure from the surface characteristics the true cause of the failure can be identified and corrective action implemented. The consequences of such action will be that proper design, certification and production methodologies will be adopted to ensure that the true structural capabilities and low maintenance costs which are possible when the technology is applied correctly, are fully attained.

Efforts are being developed with manufacturers in order to test specific adhesives for severe applications. In addition, mathematical methods and laboratory tests are being developed to represent the deboning of bonded joints.

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9. RESPONSIBILITY NOTICE

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