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Analysis of the Layer Interface of a Polymeric Composite Applied In Oil Pipelines

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ABSTRACT
The oil & gas industry has face equipment corrosion challenges due to the chemical characteristics of contaminants in the reservoirs. A three-layered composite was developed, made up of glass fiber, epoxy and polyurethane, for the production of pipelines of oil wells as an alternative to API 5L steel, which was more susceptible to corrosion. In this work, samples of pipes made of this composite were collected in oil wells, which have been operating with this material. The interfaces between the layers of the samples were analyzed through scanning electron microscopy (SEM) because the interfacial area between the layers is a critical region and can affect the properties of composite materials and compromise their applicability. The results pointed to a good adhesion in the interface between the inner and intermediate layer of all samples, but a low adhesion in the interface between the intermediate and outer layer. A deficiency in the coverage of the fibers with resin was also observed in all samples. This shows that the interfacial adhesion between the layers and the wettability of the fibers with resin should be improved to ensure a perfect distribution of stresses between the matrix and the reinforcement and to avoid future failures.

KEYWORDS: *interface, composite, oil pipe, fiberglass, epoxy.*

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I. INTRODUCTION

The oil exploration industry is hindered significantly by the corrosive process due to the complex characteristics and composition of the fluids in oil reservoirs. Mature terrestrial fields (with long production periods) have the characteristic of possessing enough water and other corrosive agents along with the oil, such as O_2, CO_2, H_2S and sulfate-reducing bacteria, which tend to attack the steel piping from the inside, in addition to the soil and atmosphere, which also tend to cause external corrosion in equipment like production pipelines.

For some years already, composite materials have been consolidated as an alternative to be used in corrosive environments, replacing metal alloys because they combine the properties of more than one material.[1] Their structural characteristics promote attractive property combinations, such as low density, high specific resistance, high modulus of elasticity, and high chemical resistance, which enable the manufacture of parts with complex geometries and high resistance to corrosion and degradation in various industrial environments.[2]

Glass fiber reinforced polymer matrix composites (GFRP) are the most common in this category. The main advantages of these composites are their low cost, good tensile strength, good chemical resistance and excellent insulating properties. The disadvantages are their relatively low modulus of elasticity, high density (of the commercial fibers), sensitivity to abrasion during handling (which often reduces tensile strength), relatively low fatigue strength and high hardness (which causes excessive wear in molds and cutting tools).[3]

In general, several factors are of influence on the mechanical behavior of composites. These factors include the manufacturing process used, the manner in which the loads are applied, the developed damage mechanism, the presence of adverse humidity and temperature conditions, the respective volume fractions, the properties of the interface, the presence of voids, in addition to the properties of the constituent elements.[4]

The fiber/matrix interface is one of the main factors influencing the mechanical properties and failure mechanisms in composite materials, and it should be analyzed carefully to ensure a good mechanical behavior of these materials. The performance of the interface is influenced by such properties as the interfacial shear strength, the interfacial fracture toughness, shrinkage of the matrix and the interfacial friction coefficient. A good adhesion (attractive forces between atoms or surfaces) of the interface depends on such factors as good interfacial energy, through the presence of functional groups on the surface of the fiber, orientation, atomic arrangement and properties of the reinforcement, chemical properties of the matrix, the diffusibility between layers, etc. This good adhesion will be responsible for making sure the interface effectively transfers the loads of the matrix to the reinforcement when the composite is used.[5]

The objective of this work is to use SEM tests to evaluate and learn about the interface between the layers of oil pipeline samples made of a newly-developed, three-layered polymeric composite operating in mature oil fields. This study may assist in the prevention of future failures of this new material due to changes in the interface, which may harm its properties, and therefore help avoid problems with operational, personal and environmental accidents.

II. EXPERIMENTAL DESIGN

Materials

In 2010, a three-layered composite (Figure 1) was developed for pipelines of terrestrial oil wells as an alternative to Grade B API 5L steel, which was commonly used and more susceptible to corrosion and failures that may cause environmental, operational and personal damage. This composite was produced through the filament winding process, which is characterized by high dimensional control and mechanical strength.

The material has an inner layer made of a glass fiber reinforced epoxy polymeric matrix, an intermediate layer of a glass fiber and silica reinforced polyester matrix and an outermost layer coated with high density polyurethane. The material was specified for 3-inch pipes, a maximum operating pressure of up to 5.17 MPa (750 psi) and a design temperature of 95 °C.[6]

The innermost epoxy layer with glass fiber is the most important layer of the material, since this is the layer that is in first contact with the pressure, temperature and characteristics of the fluid that flows through the pipeline and therefore needs to have the best properties. The intermediate polyester and silica layer is meant to improve the rigidity of the composite without the need to increase the thickness of the inner layer, saving on the final cost of the material.[6] The outermost layer of high-density polyurethane, on the other hand, is meant to serve as an insulating, mechanical and corrosive protection against agents present in the soil or atmosphere.[7]

Samples of pipes made of this composite were taken from three oil wells in three distinct fields that have been operating with this material for a few years, according to Table 1, in order to perform SEM tests and analyze the interfaces between the layers of the material.

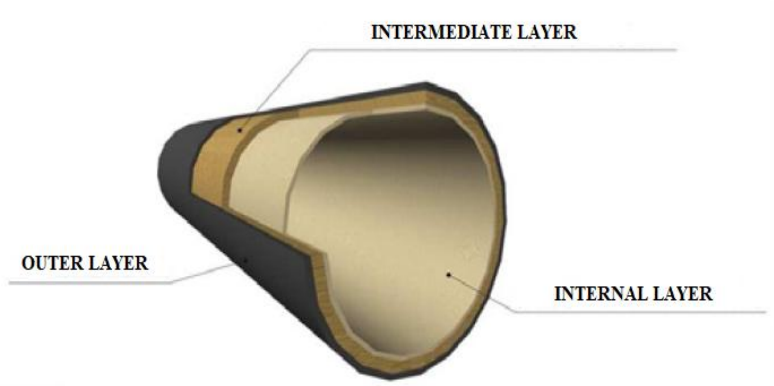

Figure 1. Three-layered polymeric composite.[6]

Table 1. Samples of composite production lines.

Sample Identification	Year of Operation
RP-0147	2012
PL-0288	2012
FP-0091	2013

III. METHODOLOGY

The samples were cut from the pipe in the dimensions shown in Figure 2 (25.4 by 25.4 mm) and submitted to a metallographic preparation by sanding the surface and removing irregularities from the cutting of the samples. The samples were then gold plated so they could become electrically conductive and be analyzed in a Scanning Electron Microscope (SEM) of the TESCAN brand, model VEGA3, in order to analyze the interface details with a large image magnification.

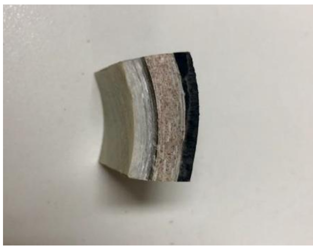

Figure 2. Dimension of the composite sample.

IV. RESULTS AND DISCUSSION

Sample FP-0091

Figure 3 shows a good interaction in the interface between the inner and intermediate layer, without the presence of a detachment or micro voids. There is spacing in the interface between the outer and middle layer (Figure 4), on the other hand, which reveals a low interaction between them. Points with exposed glass fiber without coverage of the epoxy resin were also detected (Figure 5).

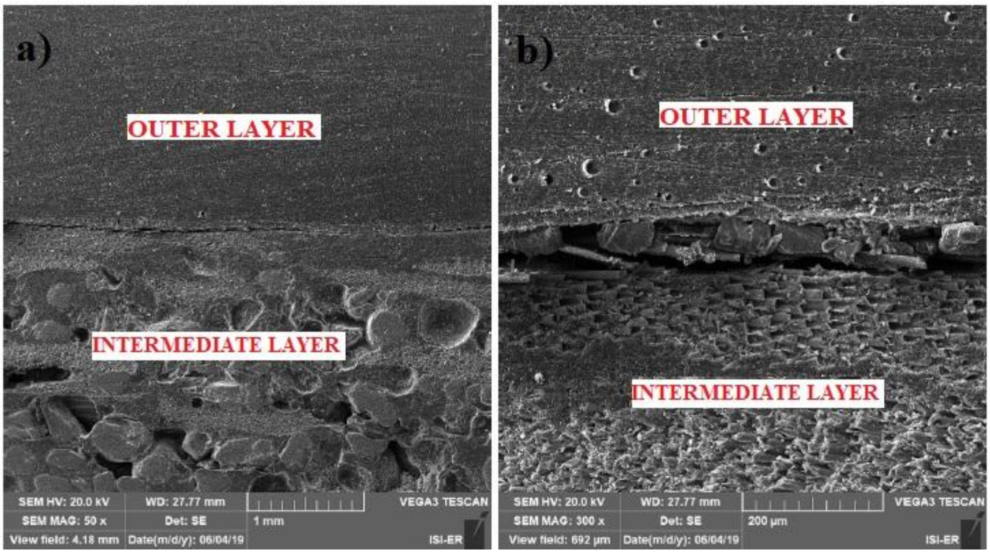

Figure 3. Interface between the inner and intermediate layer of sample FP-0091 at 50x (a) and 300x (b).

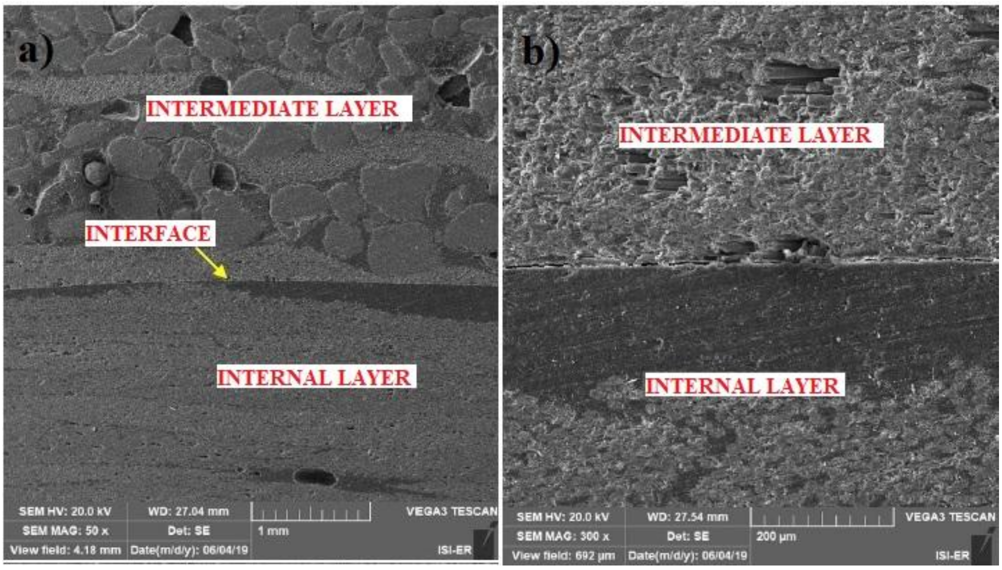

Figure 4. Interface between the outer and intermediate layer of sample FP-0091 at 50x (a) and 300x (b).

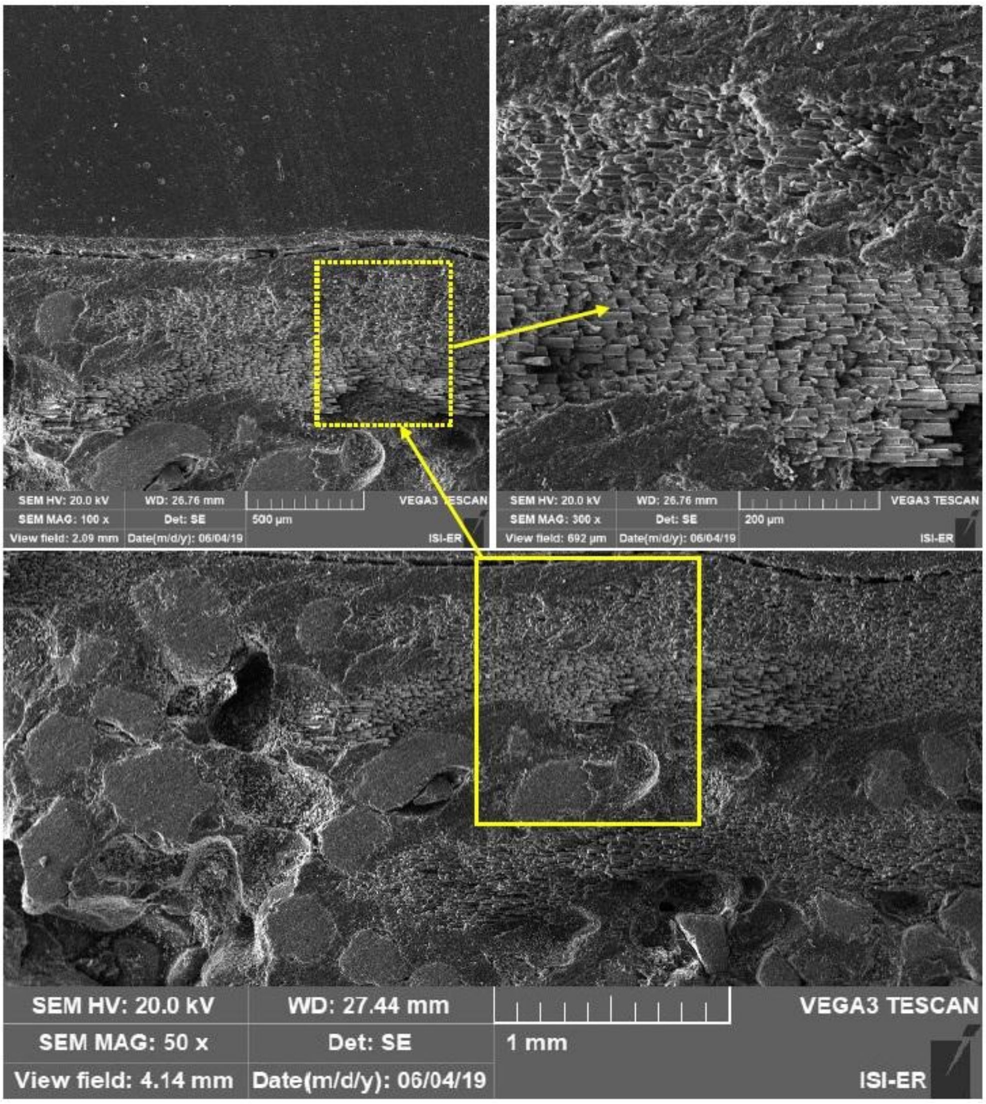

Figure 5. Points with exposed fiber in sample FP-0091 at 50x.

Sample PL-0288

Figure 6 shows a good interaction in the interface between the inner and intermediate layer, without the presence of a detachment or micro voids, but with the significant presence of exposed fibers in the intermediate layer. There is a detachment in the interface between the outer and intermediate layer (Figure 7), which reveals a low interaction between them, in addition to cracks at the interface of the intermediate layer. Figure 8 shows in more detail the points with exposed glass fiber in the intermediate layer due to insufficient covering with the polyester resin.

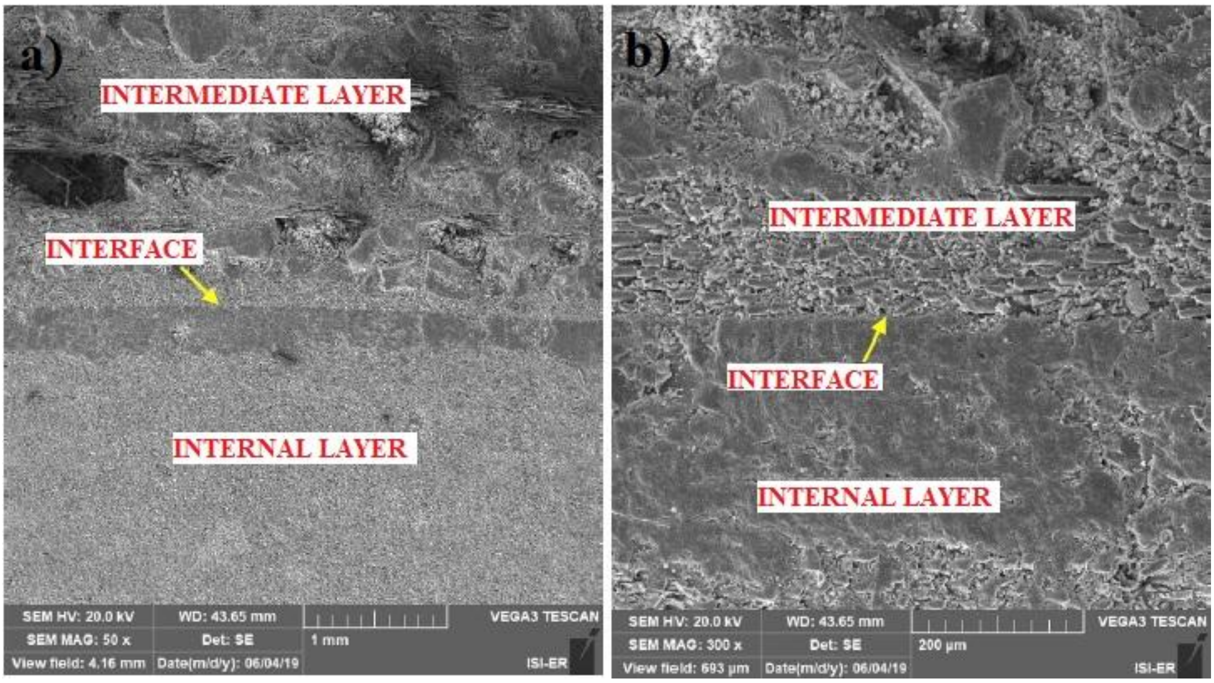

Figure 6. Interface between the inner and intermediate layer of sample PL-0288 at 50x (a) and 300x (b).

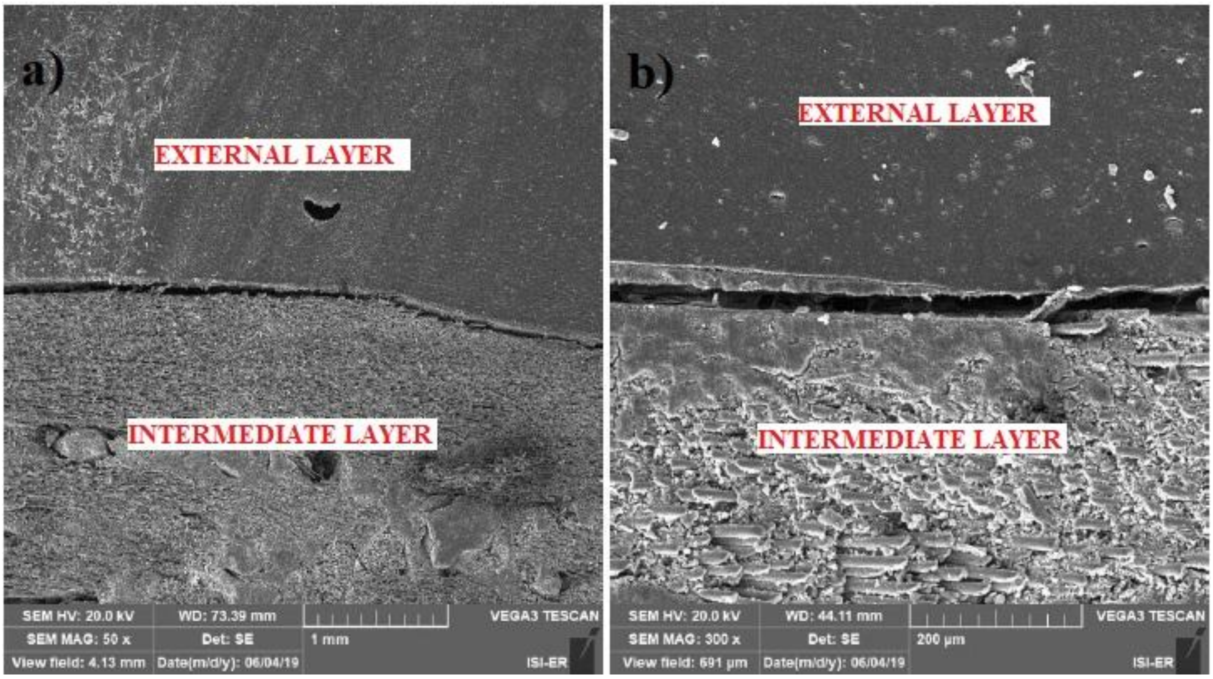

Figure 7. Interface between the outer and intermediate layer of sample PL-0288 at 50x (a) and 300x (b).

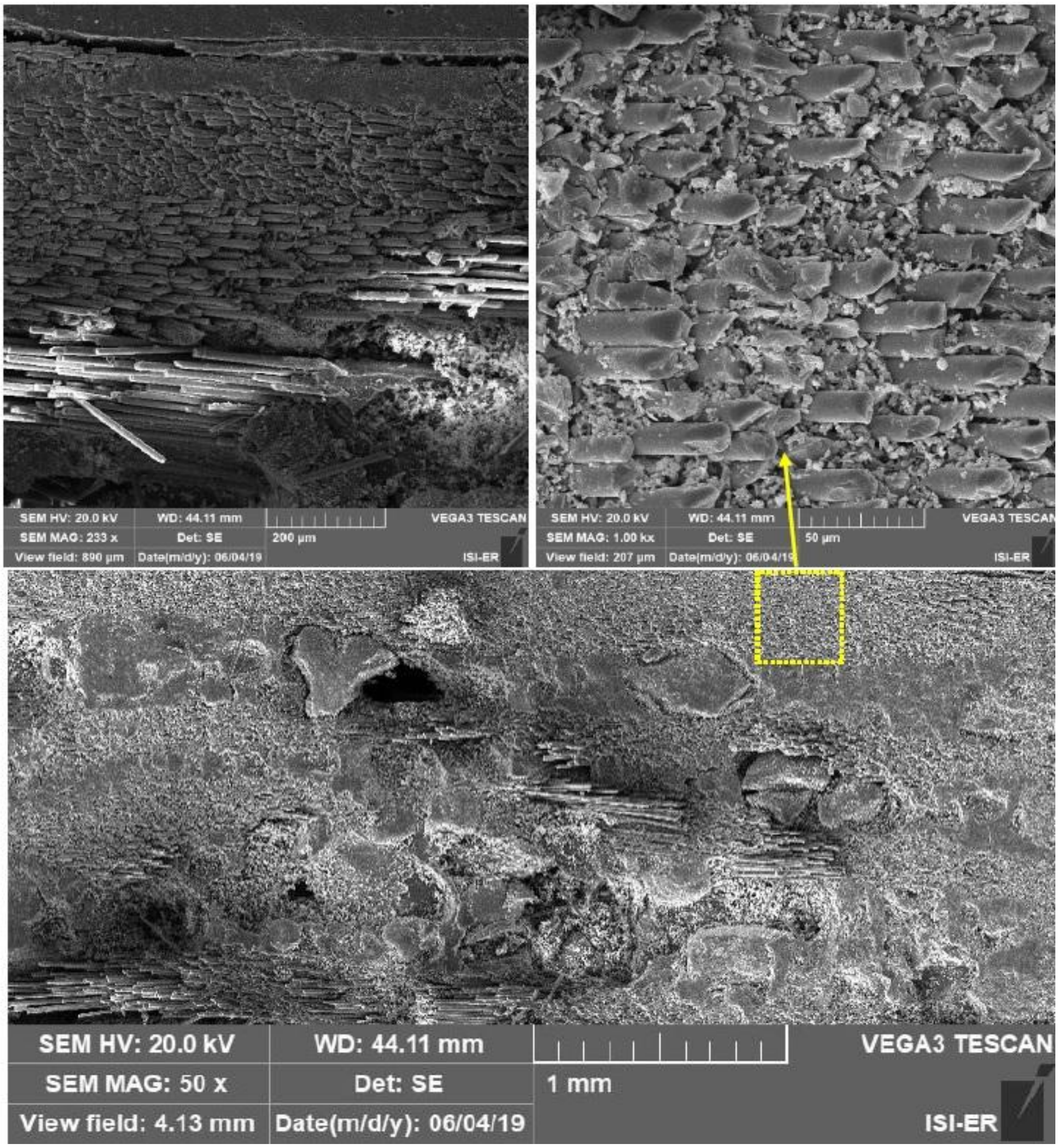

Figure 8. Points with exposed fiber in sample PL-0288 at 50x.

Sample RP-0147

Figure 9 shows a good interaction in the interface between the inner and intermediate layer, without the presence of a detachment or micro voids. This good interaction can also be seen at the interface between the outer and intermediate layer (Figure 10), but it has regions with exposed glass fiber, which also appeared in the control sample, which can be better observed in Figure 11. Unlike the other samples, this was the only one that had a good interaction between the intermediate and outer layer.

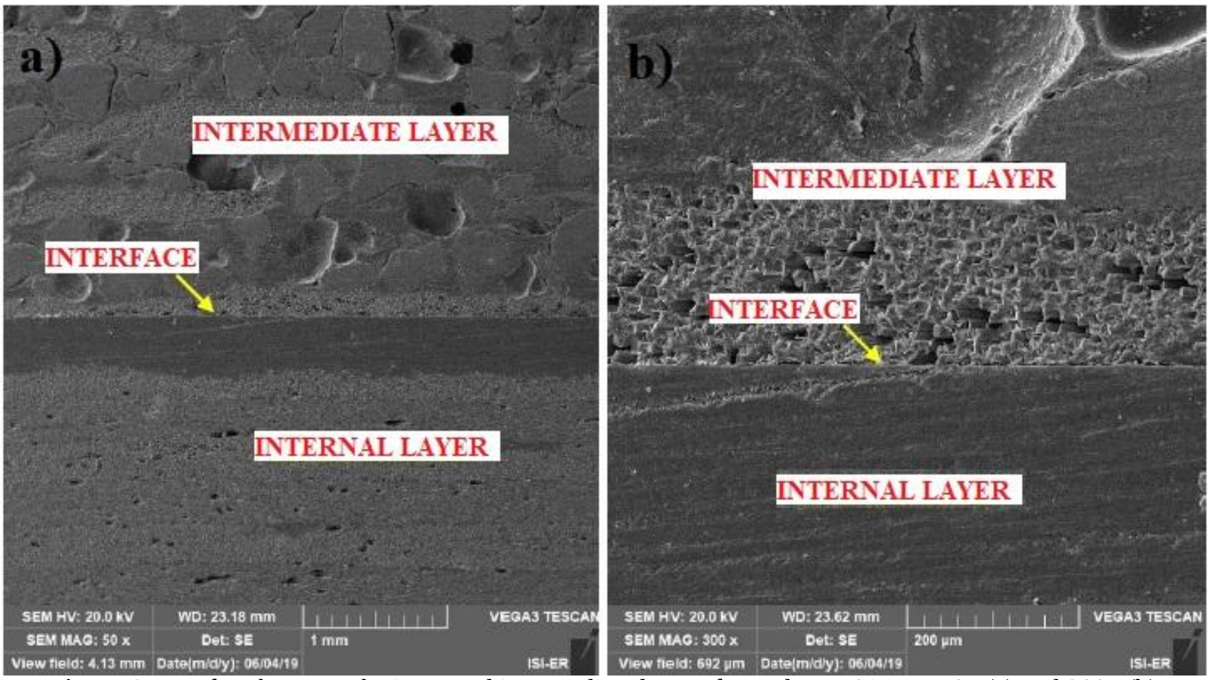

Figure 9. Interface between the inner and intermediate layer of sample RP-0147 at 50x (a) and 300x (b).

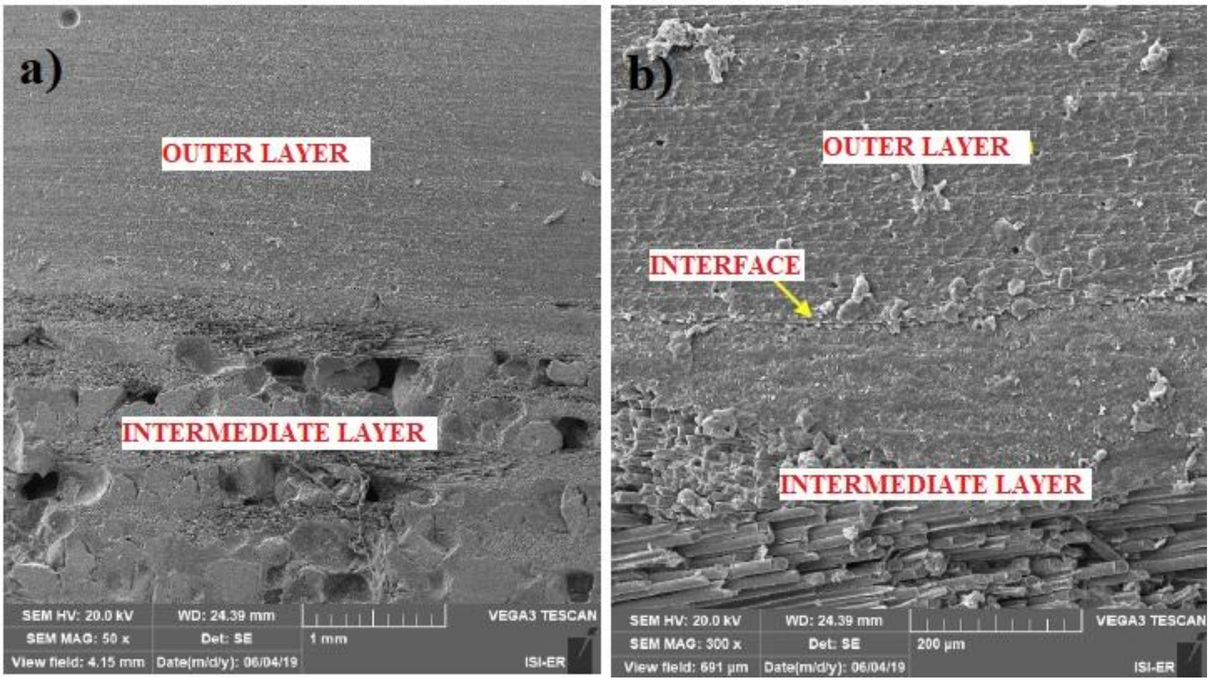

Figure 10. Interface between the outer and intermediate layer of sample RP-0147 at 50x (a) and 300x (b).

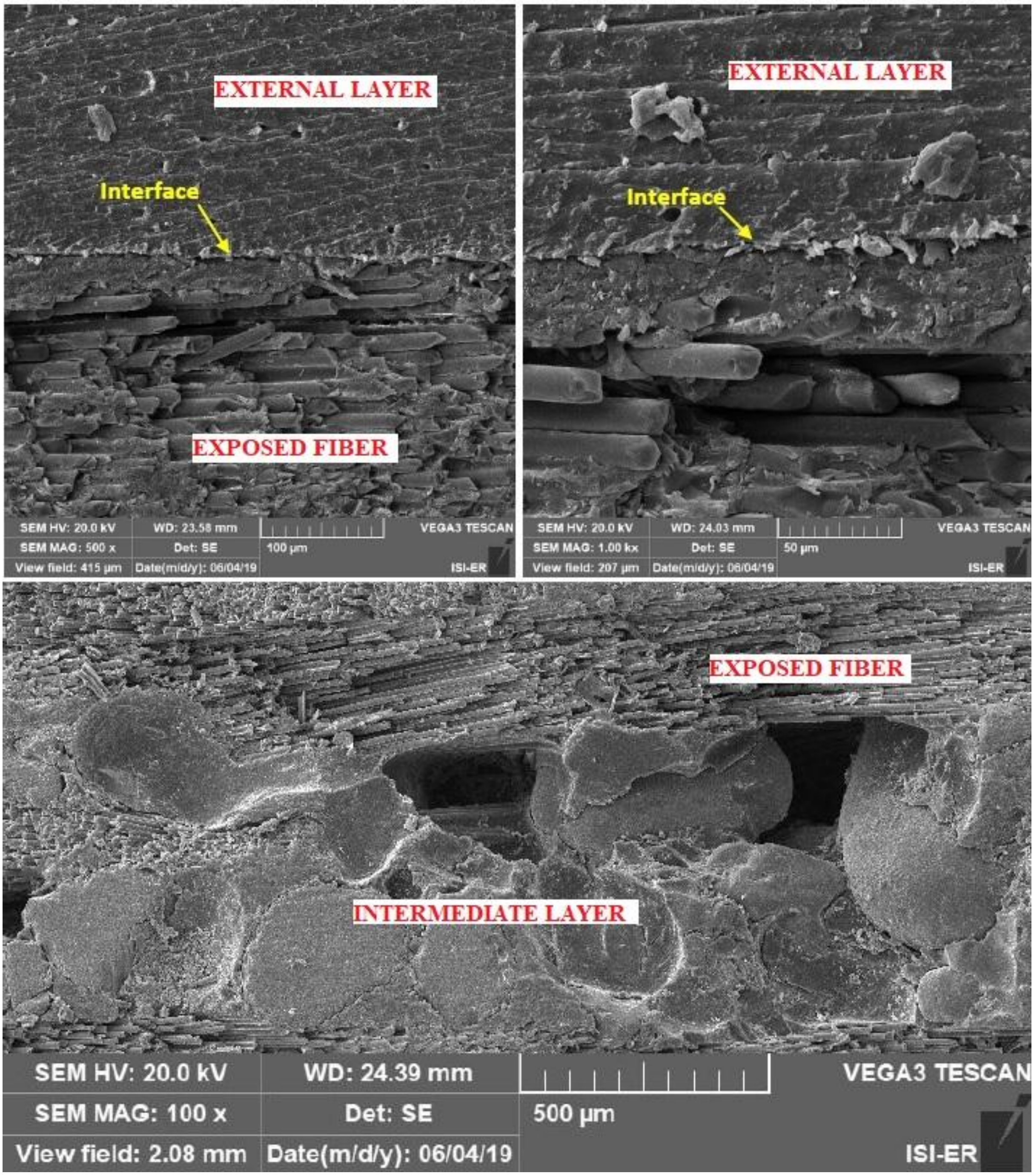

Figure 11. Points with exposed fiber in sample RP-0147 at 50x.

V. DISCUSSION

The interface between the intermediate and inner layers of the samples show a good interaction, but this does not occur at the interface between the intermediate and outer layers, which have detachments. Sample RP-0147 was the only one that had a good interaction in this interface. New samples of this material already reveal these problems, which shows that it is a problem that can be improved in manufacturing.[8]

Cracks were found in the interface regions between the intermediate and outer layers, which must have nucleated due to the stresses on the pipeline, which is subjected to internal pressure, compression of the soil and dilatation. An improvement to reduce the detachment of this interface may prevent the nucleation of cracks, since interfaces are preferred regions for the nucleation of defects.[9]

An insufficient coverage of polyester resin was also observed in the intermediate layer, exposing the glass fibers. This problem can affect mechanical properties (inefficient load distribution between the reinforcement and the matrix) and can also favor the appearance of defects.[10]

VI. CONCLUSION

It is important to study the properties of new materials in real-life situations in the field to understand their behavior and prevent failures that may cause personal, environmental and operational damage (especially in the petroleum industry). These failures are often difficult to predict in the development stages of the material.

The interface between the inner and intermediate layer showed good interaction in all samples in the microscopic analyses. The interface between the intermediate and outer layer, on the other hand, revealed the presence of voids, not enough resin on the fibers and relevant spacings in almost all samples.

Although the outer polyurethane layer has no structural function (it serves to protect), it is essential to adopt measures in the manufacture of pipelines (such as the use of aggregates and additives) to eliminate these spacings in the interface between the intermediate and outer layer to avoid the appearance of defects and cracks that may cause future failures. This fact should be treated with care, since the interface is a critical region in composite materials and if adhesion is insufficient, this may compromise the applicability of this new material in oil production fields.

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