CHARACTERIZATION OF WELDMENTS PERFORMED THROUGH FRICTION WELDING OF PIPES WITH INTERMEDIATE RING

D.R. ALBA [1]; F.C. KROEFF[2]; D.R. PISSANTI[2]; F. MATTEI [2]; M. CHLUDZINSKI[2]; T.R. STROHAECKER[2]

[1]Instituto Federal de Santa Catarina – Câmpus Joinville, [2]Universidade Federal do Rio Grande do Sul – Laboratório de Metalurgia Física LAMEF/UFRGS

Instituto Federal de Santa Catarina – Câmpus Joinville

Rua Pavão, 1377, Costa e Silva, Joinville – SC – Brazil

Postal code: 89220-618

diego.alba@ifsc.edu.br

ABSTRACT

Friction welding is a method of joining metals in which do not involve fusion, providing less microstructural modification and better mechanical and corrosion resistance. Based on this concept, a recently new and promising method for fully automatic joining of pipelines has been developed. A new equipment was designed, manufactured and tested for welding pipes using a rotating intermediate ring to generate the necessary heat for welding. The materials tested on the equipment were a steel with good weldability properties (ASTM A36), and a material with widespread use in the Oil & Gas Industry, the duplex stainless steel UNS 32205. These materials were joined and metallurgical characterized by optical microscopy. It is shown that the processed zone is divided mainly in two regions, TMAZ and HAZ. Furthermore, the most important outcome, which is welds free of voids, was reached.

KEY WORDS: Friction welding; Girth weld; Duplex Stainless Steels; Pipeline; Optical microscope

INTRODUCTION

The decrease in reserves of oil and gas in shallow water have led to the exploration of deep-water fields, where more stringent requirements are placed on the field of welding specifications. In addition, increased costs are involved in the installation of conventional deep-water production facilities. The most economical and least stressed method for laying pipelines demands a quick, time saving, welding procedure [1].

Single wire mechanized gas metal arc welding (GMAW) remains the dominant pipe girth welding technique, and has been optimized in the past to produce the maximum productivity possible with this process [2]. There have also been significant investments in “one-shot” and power beam processes in the attempt to achieve an increase in efficiency compared to SMAW and GMAW. Despite extensive development efforts, these processes have so far failed to achieve widespread benefits for pipeline construction applications [1; 3].

Aiming an automated process of union, it was proposed the development of a device for pipe joint using the method of friction welding, name Friction Welding of pipelines with rotatory ring (FRIEX) [3]. Different from conventional methods of fusion welding, friction techniques are a tool with intrinsic advantages. The joints are processed on automated equipment, ensuring control and quality. Moreover, the run times and setup are extremely lower than the conventional methods. This new process can be used in the production of joints of dissimilar materials and low weldability [4].

In order to develop the technology of union pipes by friction in Brazil, LAMEF (Physical Metallurgy Laboratory), with experience in producing high capacity and friction welding equipment, designed, built and patented a Friction Welding Machine for pipes, named MASF 1500 [5; 6]. The equipment design was developed by analyzing data collected with the performance of unions achieved with a similar welding process [7; 8]. The results allowed obtaining data to design the new equipment, such as welding strength, ring rotation, power engines and pipes burn off. The geometries employed in the pipe segments and intermediate ring were investigated [4].

FRICTION WELDING OF PIPELINES WITH ROTATORY RING

Based on the concepts of the firstly developed friction welding processes for pipes, inertia friction welding, the friction welding of pipelines with intermediate ring process was proposed [911]. The friction welding process does not involve fusion of the material and uses a ring to produce heat between the pipes that are going to be joined. These pipes are compressed against the ring, with specific load and rotational speed to perform a sound weld [3].

After the components are brought into contact, friction between the rotating ring and the pipes increases the temperature in the contact areas, until the forge temperature is reached. At that moment, the rotation of the ring is rapidly stopped, and the axial force is increased to the final forge force. A schematic illustration of the process is shown in Figure 1. Due to the fact that this process consists of joining the pipes without melting the joining partners, it implies a better quality of the join [4; 12].

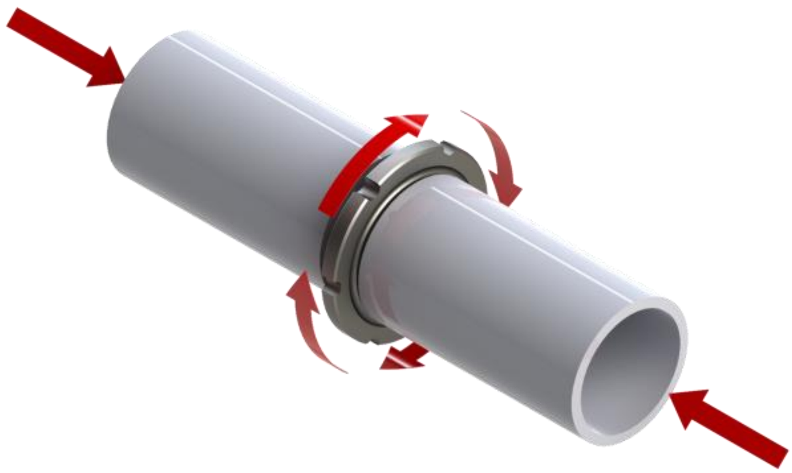


Figure 1: Schematic illustration of the friction welding process with rotatory ring for pipelines [12].

EXPERIMENTAL PROCEDURE

Test set-up

The feasibility of this new welding process has been investigated by the means of full-scale experiments. Like previously described, based on preliminary studies the equipment for the process was designed, manufactured and assembled, as shown in Figure 2 [5; 6].

The equipment is suitable for welding pipe segments with a diameter up to 406 mm (16”) and 12 meters long. The rotation of the welding ring is realized using six electrical motors of 50 HP, each connected to a gear system, which are mounted on a central placed large gear transmission. The welding ring is mounted in the large hollow gear wheel of the gear system, in a rigid clamping device able to transmit the drive power and torque. The maximum rotation speed of the welding ring is 500 rpm. The available effective drive power is equal to 300 hp.

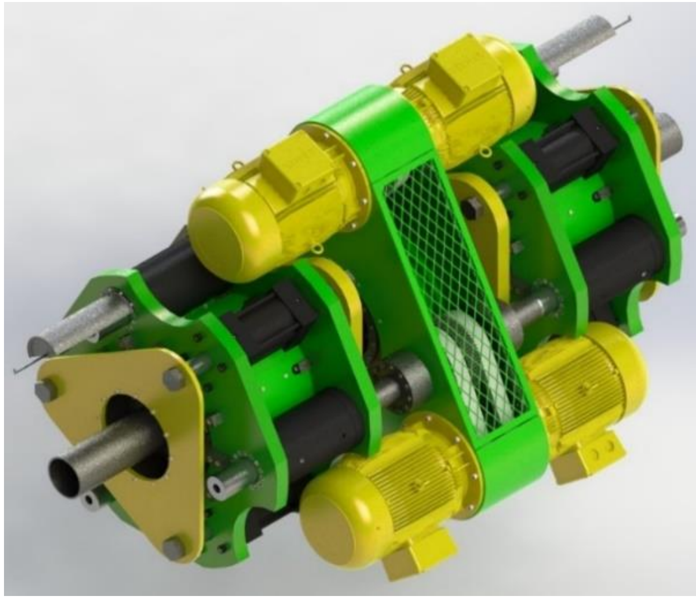


Figure 2: MASF 1500 equipment for friction welding of pipelines located at LAMEF.

Materials

For the experiments and commissioning of the equipment, as a first step were performed weldments in materials with high weldability. Furthermore, a widespread material on oil and gas industry was welded and characterized.

ASTM A36 is the most commonly used mild and hot-rolled steel. It was introduced in the 1960s and since there is very popular for structural applications. Due to its high weldability and moderate strength, A36 steel is the principal carbon steel for bridges, trusses and many other structural uses [13; 14].

Duplex and super duplex stainless steels are specified for applications where best corrosion resistance is required. These grades combine the advantages of ferritic and austenitic steels thus providing high strength, improved fatigue and corrosion resistance and better resistance to Stress Corrosion Cracking. UNS 32205 is the most widely used duplex (ferritic/austenitic) stainless steel grade. It finds applications due to both excellent corrosion resistance and high strength [15; 16].

Table I shows the materials for rotatory ring and pipe, all of them in similar welding configuration, and its chemical composition analyzed through atomic emission spectrometry.

Table I: Chemical composition of the materials welded in MASF 1500 (% in wt.).

Material	%C	%Mn	%Si	%Cr	%Mo	%Ni	%Cu
ASTM A36	0,15	0,91	0,17	--	--	--	0,52
UNS 32205 Duplex steel	0,02	1,61	0,51	23,1	3,17	5,48	0,23

Figure 3 shows the pipes and rotatory ring before the welding experiments.

Figure 3: Pipe and ring specimens.

The dimensions of pipes and ring are presented in Table II.

Table II: Pipes and rings dimensions welded in MASF 1500.

Material	Outer diameter [mm]	Thickness [mm]	Ring length [mm]
ASTM A36	219.08	19.05	25.4
UNS 32205 Duplex steel	150.20	12.70	25.4

The welding parameters for the experiments are presented in Table III. The choice of these parameters were based in preliminary tests.

Table III: Welding parameters utilized in each material for the experiments.

Material	Rotational speed [rpm]	Burn off [mm]	Forging Force [kN]	Forging time [s]
ASTM A36	500	10	210	30
UNS 32205 Duplex steel	500	20	Max. Force during process	120

For metallographic investigation, transverse sections of the friction welded samples were cut, grinded and polished. All optical microscope samples were prepared following a standard procedure for steels preparation. The samples were etched with Nital 2% for the ASTM A36 steel and with Modified Behara etching solution for the UNS 32205 steel. The analyses were carried out using an Olympus PMG 3 Optical Microscope.

RESULTS AND DISCUSSIONS

Figure 4 shows a typical weldment performed by MASF 1500. It is possible to see the typical flash formation due to the severe plastic deformation and temperatures profiles that the pipe and ring are submitted. Further discussions regarding the microstructure of the weldments are described in the sections below.

Figure 4: Weldment with consumable rotatory ring performed in MASF 1500.

ASTM A36 steel

The microstructural analysis was performed in the ASTM A36 weldment to determine the distinct regions that were originated during the experiment. Figure 5 presents the regions analysed. The index on the illustration shows the location were the micrographs were made. Note that just a small amount of pipe material converted in flash on the weldment. Furthermore, the consumable ring was not fully consumed during the process. This could be explained due to the lack of heating generation during the process. In addition, a misalignment between both pipes was observed. However, no defects or cracks were observed in the welding region of the weldment.

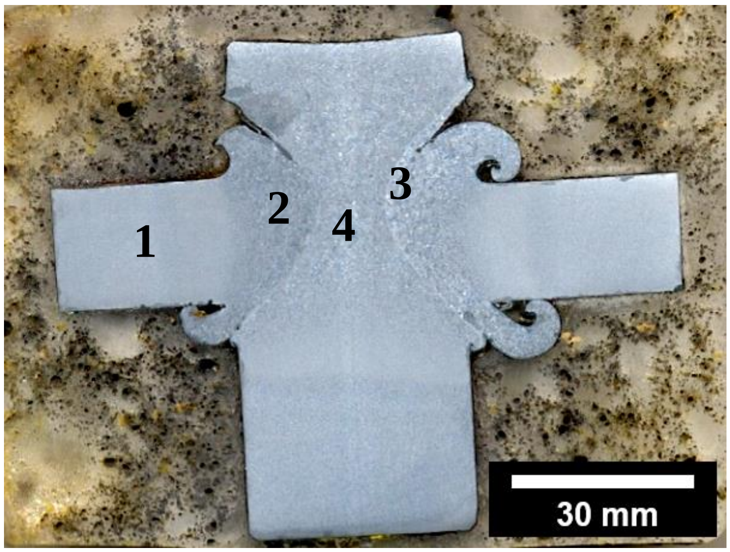
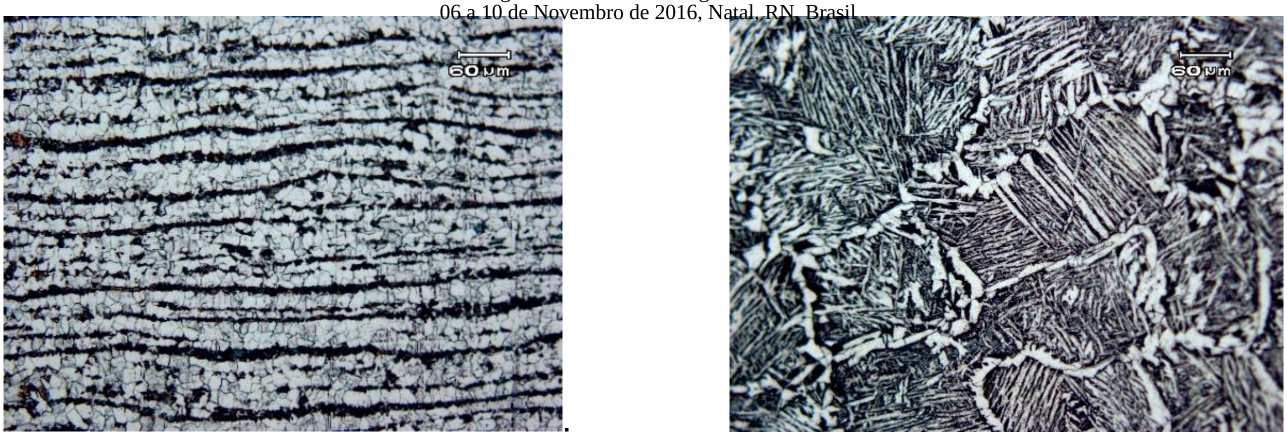


Figure 5: Macrograph of the weldment performed in ASTM A36 steel and the subsequent analyzed regions.

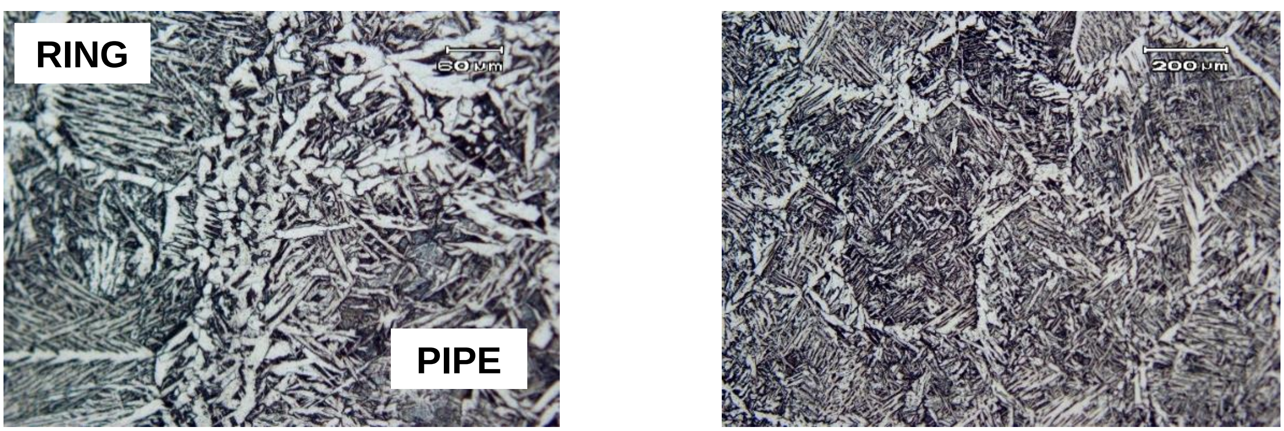
Figure 6a, shows the microstructure of the base material (Region 1). Polygonal ferrite grains (white) with pearlite colonies (black) aligned on the rolling direction compose the microstructure. The process does not modify this region. The adjacent region (Region 2) is composed by HAZ (Heat Affected Zone) and TMAZ (Thermo Mechanical Affected Zone) of the pipe. Due to the thermal gradient and plastic deformation the elongated orientation of the ferrite and pearlite was modified and is composed by coarse grains of acicular ferrite and carbides. It was observed the appearance of allotriomorphic ferrite on the grain boundaries and Widmanstätten ferrite. An allotriomorph has a shape that does not reflect its internal crystalline symmetry. This is because it tends to nucleate at the austenite grain surfaces, forming layers which follow the grain boundary contours. This microstructure indicates that this pipe region was exposed to high temperatures, because the Widmanstätten and acicular ferrite occur when the austenitic microstructure is submitted to rapid cooling. Figure 6b presents the microstructure of this region.



(a) (b)

Figure 6: (a) Microstructure of the ASTM A36 base material – Region 1. (b) Microstructure of the TMAZ of the pipe – Region 2. (Nital 2%)

Region 3 (Figure 7a) presents the interface between pipe and ring. Coarse acicular ferrite grains, carbides inside the grains, allotriomorphic ferrite and Widmanstätten ferrite on the grain boundaries compose this region. The pipe shows a larger amount of acicular ferrite while the ring microstructure presents more Widmanstätten ferrite. Thereby, it indicates that the cooling rate of the pipe is faster than the one faced by the ring. Finally, Region 4 (Figure 7b) is the ring TMAZ, the region that is exposed to severe plastic deformation and temperature gradients. Acicular ferrite and carbides compose the observed microstructure. There is the occurrence of Widmanstätten ferrite and allotriomorphic ferrite on the grain boundaries. This region also presented grain growth.



(a) (b)

Figure 7: (a) Microstructure on the interface region between pipe and ring - Region 3. (b) Microstructure of the TMAZ of the ring – Region 4. (Nital 2%)

Duplex Stainless steel UNS 32205

Figure 8 presents a macrograph of the weldment on the Duplex Stainless steel UNS 32205. The index on the illustration shows the location were the micrographs were taken.

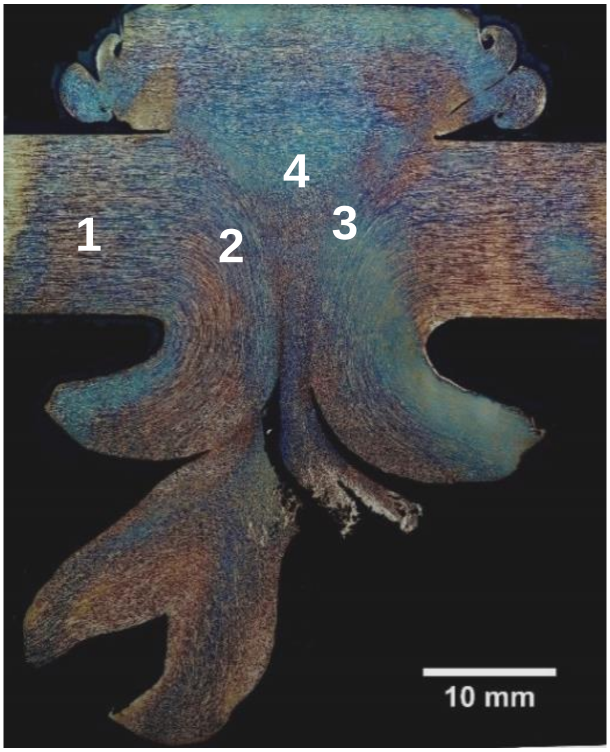


Figure 8: Macrograph of the weldment performed in UNS 32205 steel and the subsequent analyzed regions. (Modified Behara)

It is observed that during this weld, the consumable ring was almost fully consumed and there was a notable formation of flash during the process, indicating a bigger heat generation on the interface. Likewise, the welding of the ASTM A36 steel, this weldment did not present cracks or defects on the interface region. Figure 9 presents the base material of the pipes. The picture shows a microstructure composed by a ferritic matrix (blue) with elongated austenite (white) on the lamination direction.

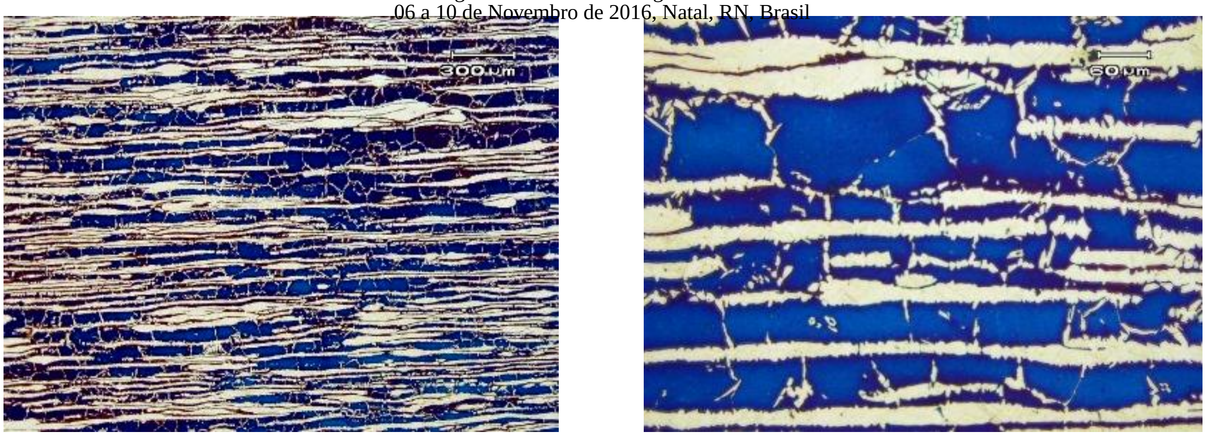


Figure 9: Microstructure of the UNS 32205 base material. (Modified Behara)

The microstructure of the Region 2 (Figure 10) is the TMAZ of the pipe. The proportion of ferrite is similar to the pipe base material. The main difference presented in this picture is inherent to the plastic flow of the material during the friction process. The austenite and ferrite are deformed according to the deformation direction.

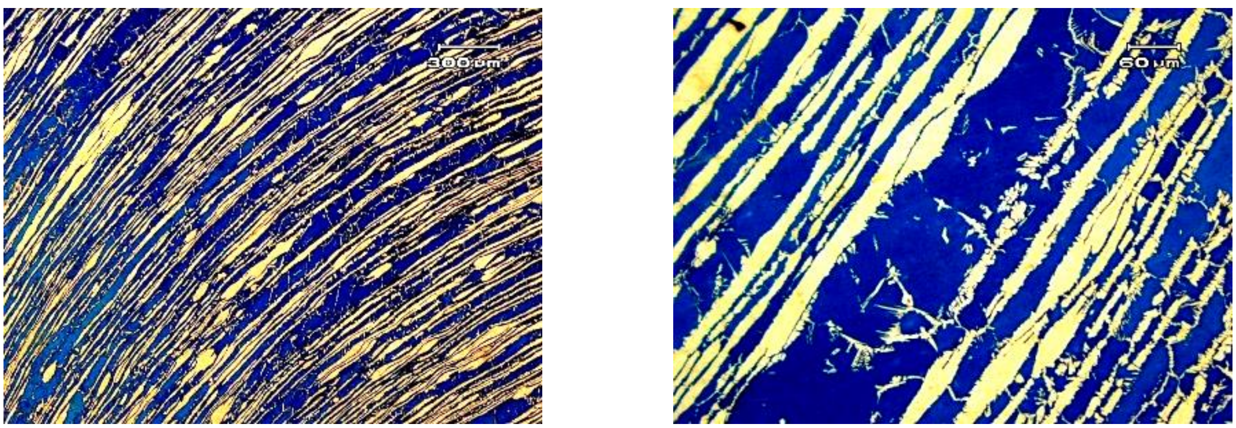


Figure 10: Microstructure of the TMAZ of the pipe. (Modified Behara)

Figure 11 depicts Region 3, showing the interface region between pipe and ring. This region of the ring is composed mainly by ferrite and alotriomorphic and Widmanstätten austenite. Furthermore, the region of the pipe is composed of ferrite and austenite lamellas with some regions of idiomorphic austenite inside the ferrite lamellas.

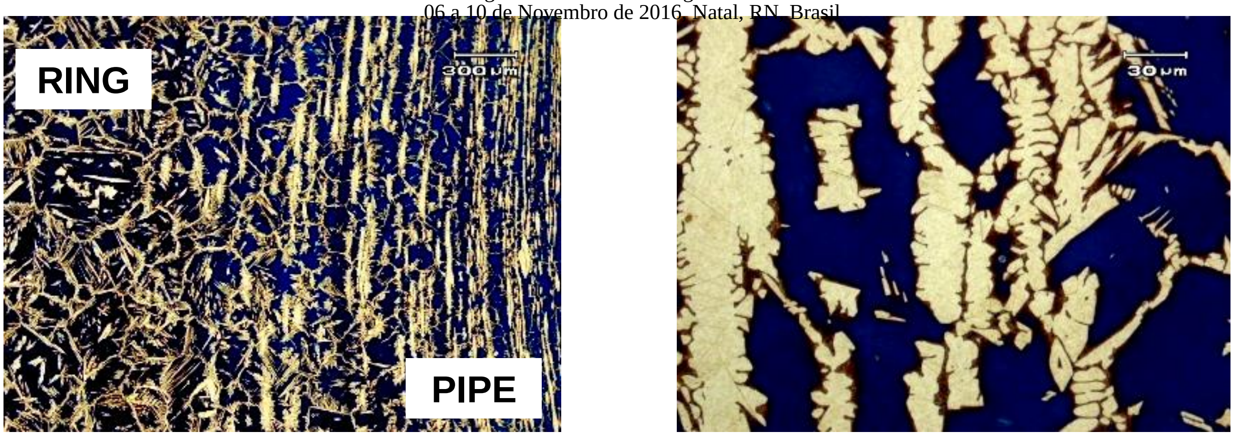


Figure 11: Microstructure on the interface region between pipe and ring. (Modified Behara)

Lastly, the Region 4 (Figure 12), the TMAZ of the ring, is the region that is entirely composed by equiaxied and acicular grains of ferrite and also allotriomorphic and Widmanstätten austenite. On this region, there is an evident grain refinement due to the severe plastic deformation that is inherent to the process. Temperature and plastic deformation allow the recrystallization phenomenon to occur originating this refined grain structure.

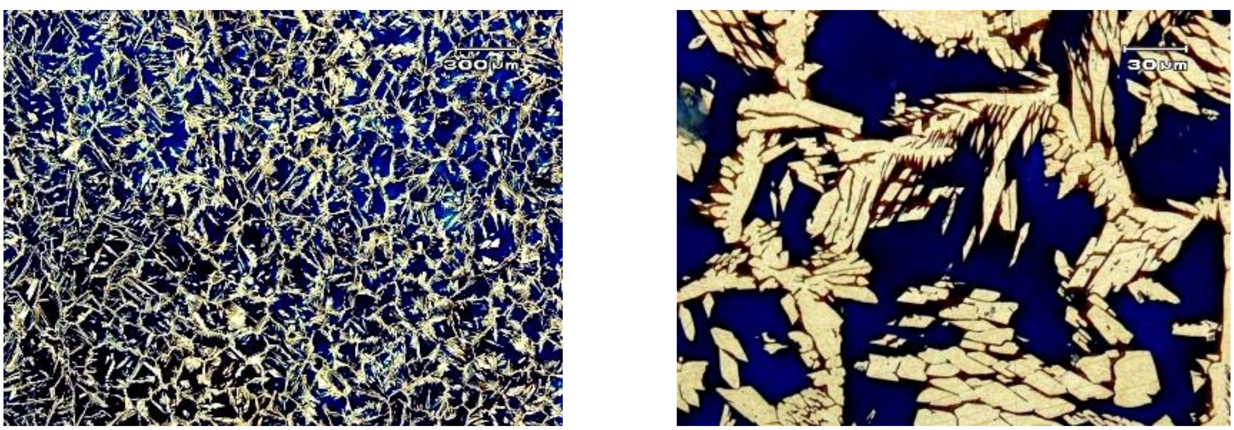


Figure 12: Microstructure of the TMAZ of the ring (Modified Behara)

CONCLUSIONS

The feasibility of the friction welding with rotatory ring has been successfully demonstrated. The study of this variant of the friction processes shows that it is suitable for joining pipes. Using the experimental test set up, welds with good quality and free of cracks or defects could be produced. As first step, the material chose for this study was a structural steel with good weldability, the ASTM A36 steel, and posteriorly was chosen a material with widespread use in Oil & Gas applications, the Duplex

Stainless Steel UNS 32205.

It is inherent the microstructure modification derived from friction processes. The heat generation and severe plastic deformation generates a microstructure very distinct from the base material. When the base material microstructure is composed by elongated grains, from the lamination processes, the process modifies its microstructure to equiaxied grains. When the base material microstructure is - normalized, the process provides a grain growth on the microstructure keeping the equiaxied morphology.

The design and manufacture of the equipment MASF 1500 are the results of a research and development of the new technique of friction welding for pipeline. The equipment is efficient considering the repeatability of the experiments. With this technique it is possible to improve the construction of pipelines mainly if considering the duration of each joint.

Additional studies are being performed to qualify the weldments of these materials in accordance to the API 1104 and DNV-OS-F101 international standards. Furthermore, the design and manufacture of a welding equipment for field operations is already in progress as well as an equipment for internal flash removal of the weldments.

ACKNOWLEDGMENTS

The authors would like to thank Petrobras and ANP for the support.

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