Development of the FRIEX welding process

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1. Introduction

Pipe joining is one of the most critical, expensive, but inefficient processes in the construction industry. Some factors that contribute significantly to the high cost of welding originate from the complexity of the welding processes and the stringent requirements. In industrial practice, the quality of the welds is highly dependent on the welder skills. Due to the fact that standards are getting more stringent, it is difficult for the welder to comply with these requirements. There tends to be a high degree of variability in the weld quality, which results in a frequent need for rework. In shielded-metal arc welding the need to shield the weld arc from impurities in the atmosphere is a source of major concern and extra expense if rework is required.

Successful implementation of advanced joining techniques for pipes could yield in significant reductions in the processing time and the need for skilled labour, in a decrease of costs associated with the welding process and in improvements in the joint quality. Several advanced welding technologies have the potential to improve the current pipe-joining practice. Magnetically impelled arc butt welding (MIAB), homopolar, induction and friction stir welding have been investigated aiming at achieving their eventual implementation for pipeline welding. Currently, a new variant of the well-known friction welding method, called Friex, has been investigated for use for automatic pipeline welding.

Figure 1 : *Pipeline welding*

2. Working principle of the FRIEX process

The Friex technology is based on the friction welding process. This is a forge welding process in which the heat necessary to realise the weld, is generated as a result of the friction forces between two surfaces rubbing against each other under controlled axial pressure. The relative motion or rubbing of the two parts is continued until sufficient heat has been generated. At that moment, the rubbing is stopped and the two pieces are forged. Most applications involve welding of round or cylindrical parts, because friction can simply be generated by relative rotation.
The disadvantage of the rotary friction welding process is that it is impossible to weld parts that cannot be rotated. This is also the case for pipelines, since the pipe sections can be as long as 18 meters. In order to be able to use the friction welding process for pipeline welding anyhow, a new variant has been developed, called the Friex process.

The major difference of the new variant with conventional friction welding is that a filler material in the form of a solid ring is used. This welding ring is placed in between the pipes, and rotating the ring under an axial pressure generates the required friction and associated heat (Figure 2).

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. After welding, the remaining welding ring material and welding flashes are removed using an automated milling mechanism.

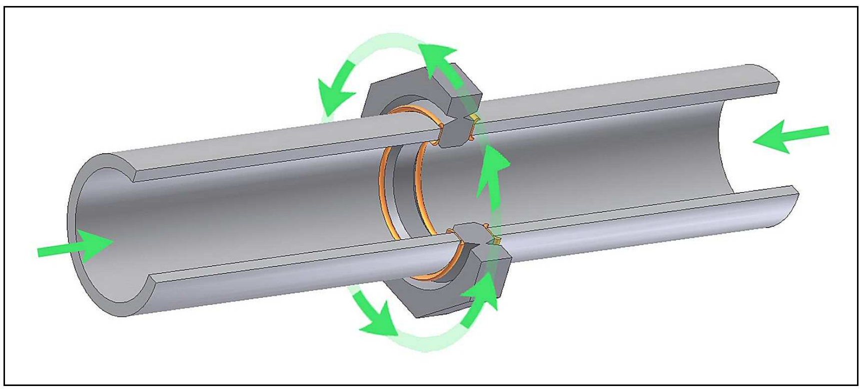

Figure 2 : *Principle of the new welding process*

3. Process development

The Friex technology has been investigated in an incremental way over the past years. The development was performed as a cooperation between the company DENYS NV, the Belgian Welding Institute (BWI) and the University of Ghent; laboratory Soete (LS). Modelling was done by the Technical University of Graz, Austria and by CENAERO (Charleroi, Belgium).

3.1. Small-scale experimental research

In a first phase (1998 - 2001), a small-scale welding machine was developed to establish a proof-of-concept, based on limited-diameter pipes (typically 50 mm outer diameter). The material used was plain carbon steel. The process parameters for welding these kind of pipes were optimised. The quality of the resulting welds was assessed by metallographic examination and mechanical testing. As a result of this phase, the weldabilty of plain carbon steel pipes with the Friex process was demonstrated.

Figure 3 : *Small-scale test set-up*

Figure 4 : *Macroscopic section of a weld*

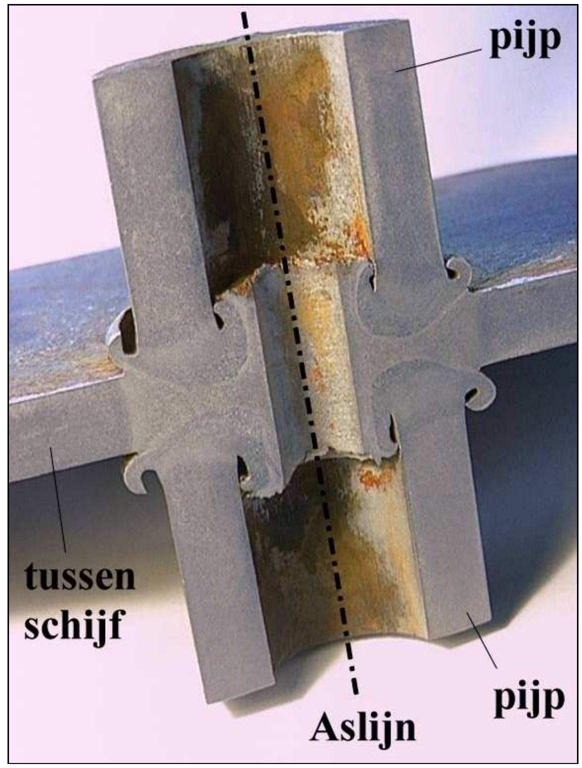

Figure 5 : *Typical small-scale weld*

3.2. Medium-scale experimental research

During the second phase (2001 - 2007), a new test equipment was constructed (Figure 6) to allow welding trials with larger diameter pipes, up to 141 mm outside diameter (5 inch). Several key topics for the further development and understanding of the technology were investigated.

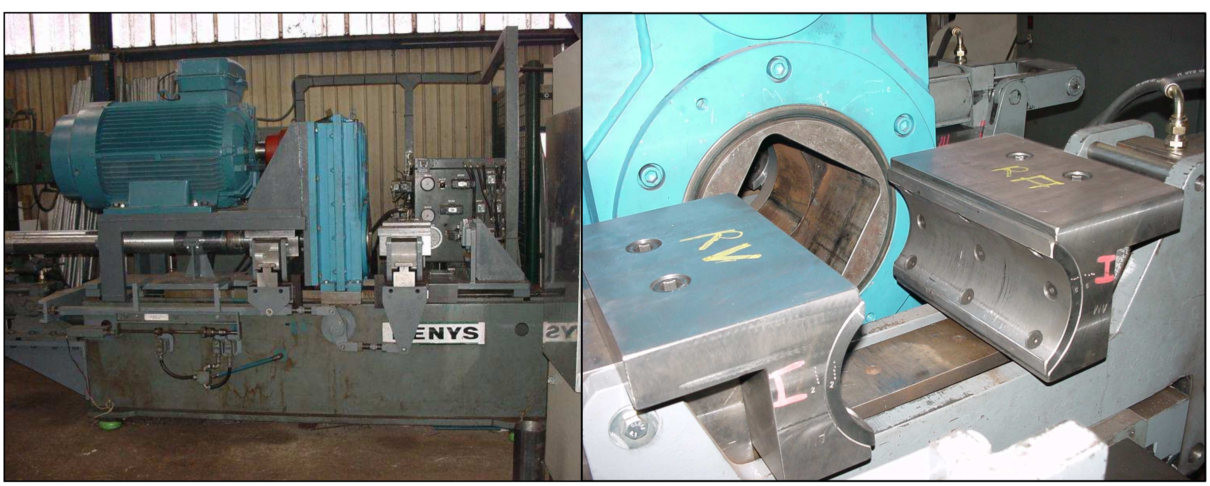

Figure 6 : *Medium-scale test set-up*

Figure 7 : *Typical medium-scale weld (4 inch pipes - O.D. : 114,3 mm; wall thickness : 8,5 mm)*

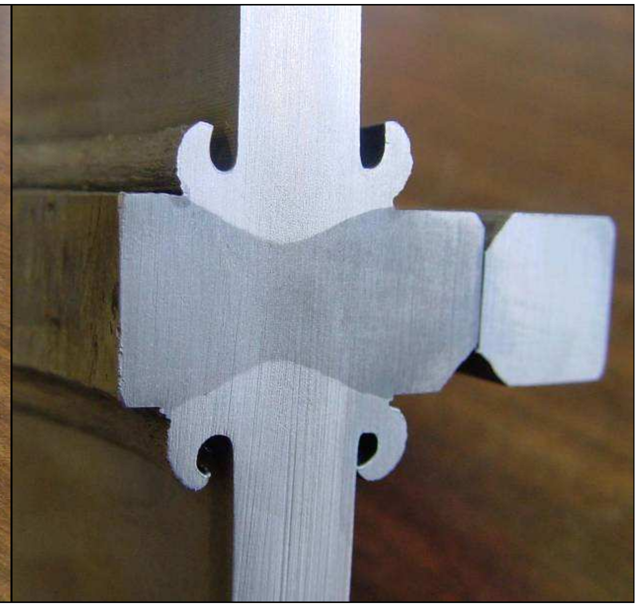

Figure 8 : *Detail of Figure 7*

The aim of this project phase was the investigation of the influence of the welding parameters (friction and forge pressure, rotation speed, welding time, dimensions of the welding ring, forced cooling, etc.) on the characteristics of welded pipes in the materials EN 10208 L290NB and L360NB (API-5L X42 and X52 - see Figure 15). For example, the influence of the welding ring thickness is shown in Figure 9 and Figure 10 and Figure 11 [1], [2], [3], [4], [5], [6], [7], [8].

The major results of the investigations on L290NB and L360NB pipes are summarised in [9], [10], [11], [12], [13].

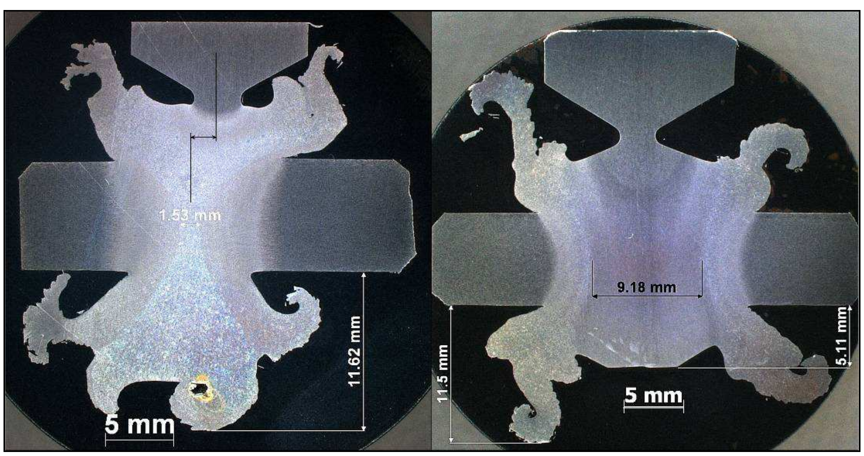

Figure 9 : *Influence of the thickness of the welding ring (left : too small welding ring - right : suitable welding ring)*

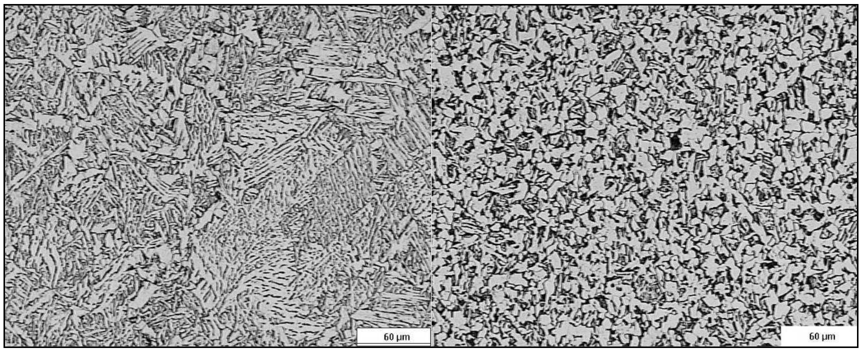

Figure 10 : *Microstructure at the weld interface of the welds shown in Figure 9*

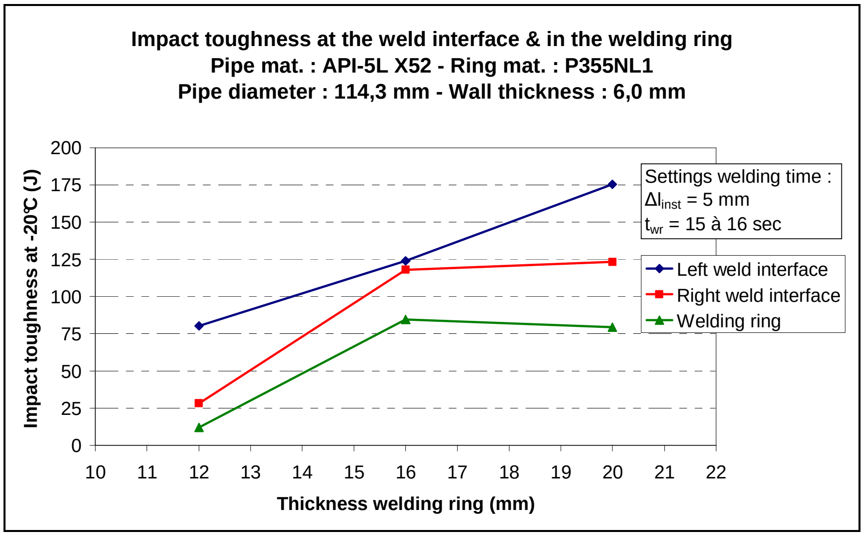

Figure 11 : *Results of Charpy impact tests*

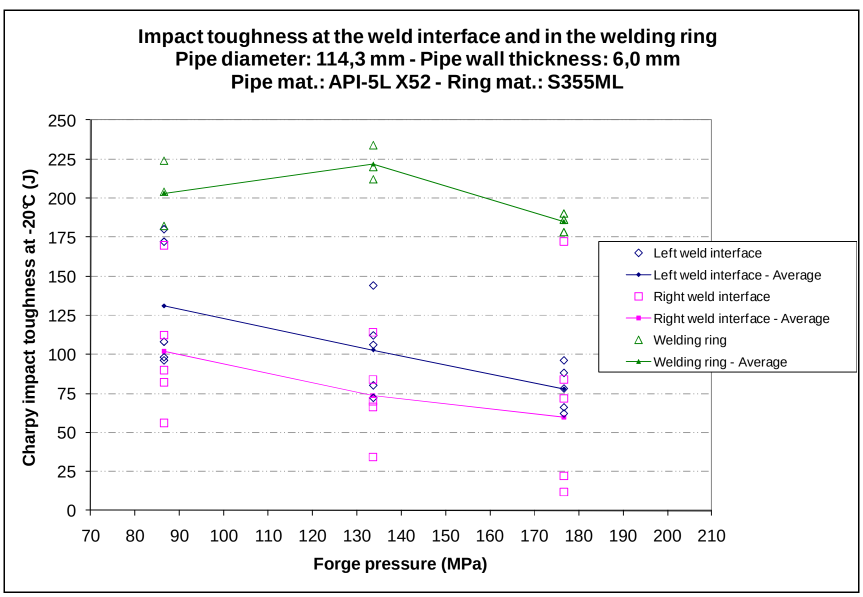

Figure 12 : *Influence of the forge pressure on the weld impact toughness*

It was demonstrated that the weld quality in general, and the impact toughness in particular, was highly dependent on the process parameters (thickness of the welding ring, rotation speed, process duration, forging pressure, …). The parameters have to be chosen within a "welding window". In-depth research was performed on establishment of these parameter windows; a challenging assignment since every individual parameter has an influence on the weld quality and because the single parameters are influencing each other as well.

There was also a modelling effort, based on finite-elements analysis techniques, to describe the friction welding processes for different product forms (diameters, various steel alloys, …) in terms of temperature distribution, heat fluxes, plastic deformation, etc. This was executed by the University of Graz (Austria), based on input data, registered during and after the welding tests. These models allowed to predict the deformation behaviour and temperature fields during welding [14], [15], [16], [17], [18], [19].

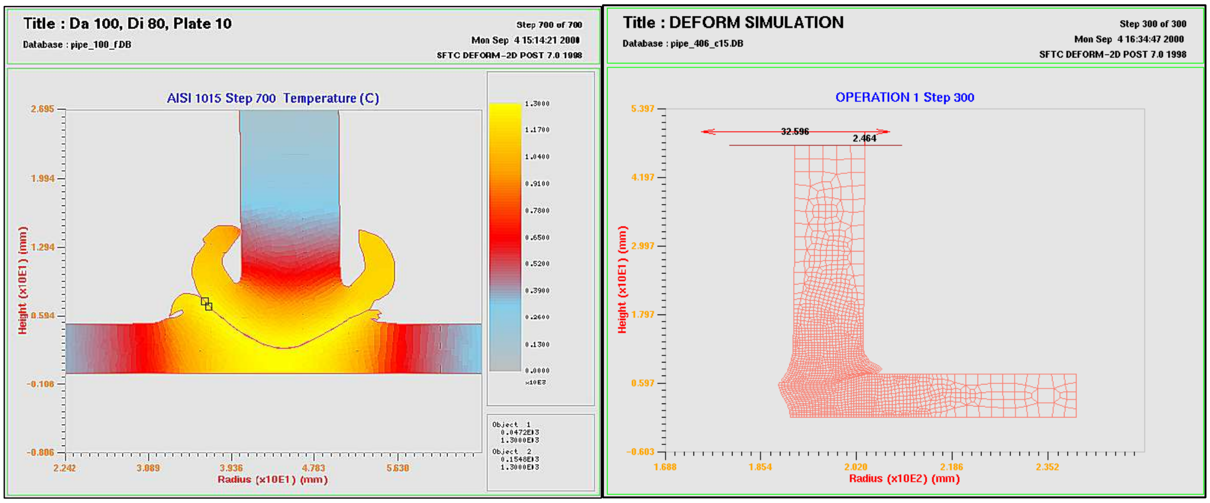

Figure 13 : *Finite-element simulation (T.U. Graz)*

The FEM models were further refined by the new partner, Cenaero of Charleroi, Belgium. The FEM-models were helpful to design the optimal form and size of the welding ring, to extrapolate the test results towards larger dimensions and to assess the influence of the modified relation between the pipe thickness in relation to the outside diameter. The resulting FEM-models from Graz University and Cenaero enable to predict the welding parameters, reducing the need for extensive testing. More underpinned decisions could be made for the design of actual welding tests.

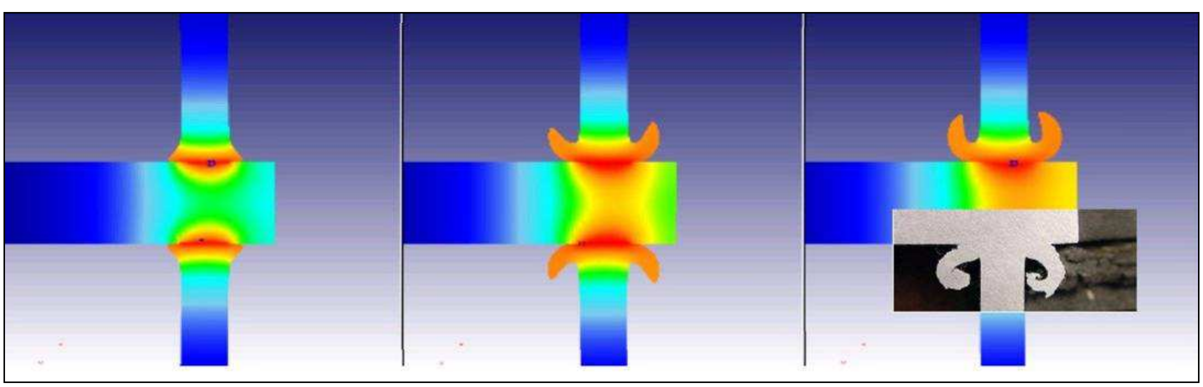

Figure 14 : *Finite-element simulation of the process (Cenaero)*

3.3. Large-scale experimental research

Previously, the feasibility of the Friex technology for joining pipes was successfully demonstrated by means of small- and medium-scale experiments. The investigation showed that the process is suitable for joining the line pipe steels L290NB and L360NB. The welds fulfilled the acceptance criteria described in the commonly used standard for pipelines welding; EN 12732 (“Gas supply systems - Welding steel pipework - Functional requirements”).

The process was scaled up to larger diameter pipes in order to evaluate the weldability of large-diameter high-strength micro-alloyed pipeline steels, such as EN 10208 L415MB, L485MB and L555MB (API-5L X60, X70 and X80 - Figure 15). A large-scale test set-up for joining pipes up to 504 mm in diameter was designed and built (Figure 16) [20], [21], [22].

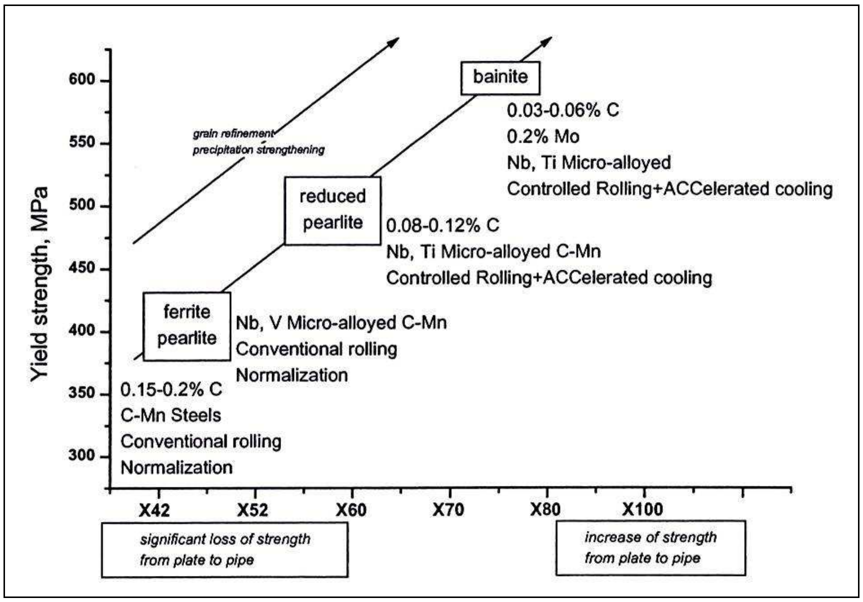

Figure 15 : *Schematic overview of existing pipeline steels, together with the fabrication processes and microstructures to achieve the desired strength and toughness*

Experimental test set-up

The machine is suitable for welding pipes with a diameter of 220 up to 504 mm. The rotation of the welding ring is realised using 6 hydraulic motors, each connected to a planetary gear system, which are in their turn 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 250 rpm. The available effective drive power and torque equals resp. 600 kW and 100.000 Nm.

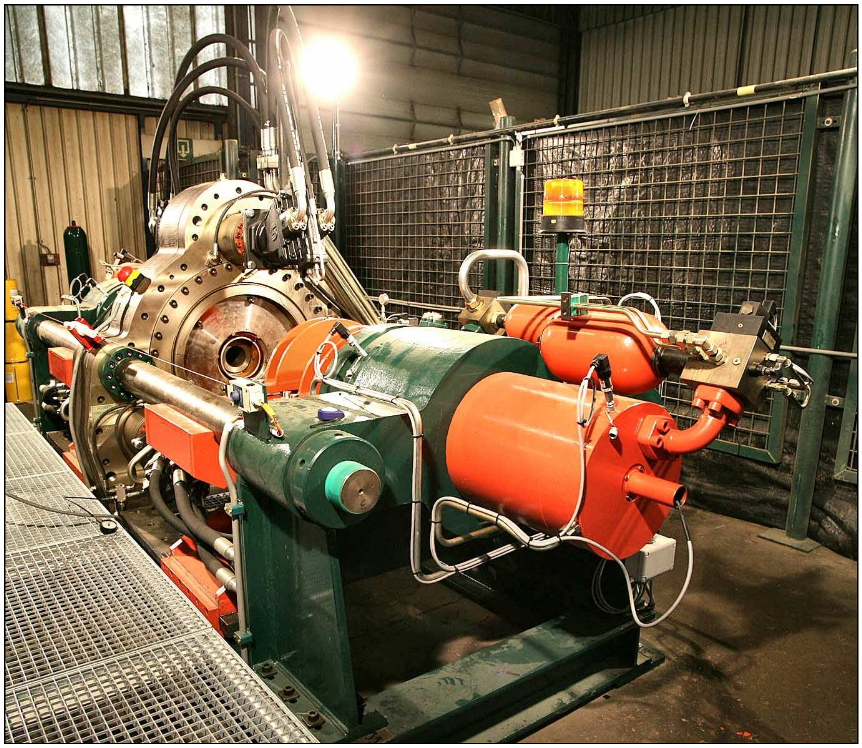

Figure 16 : *Large-scale test set-up*

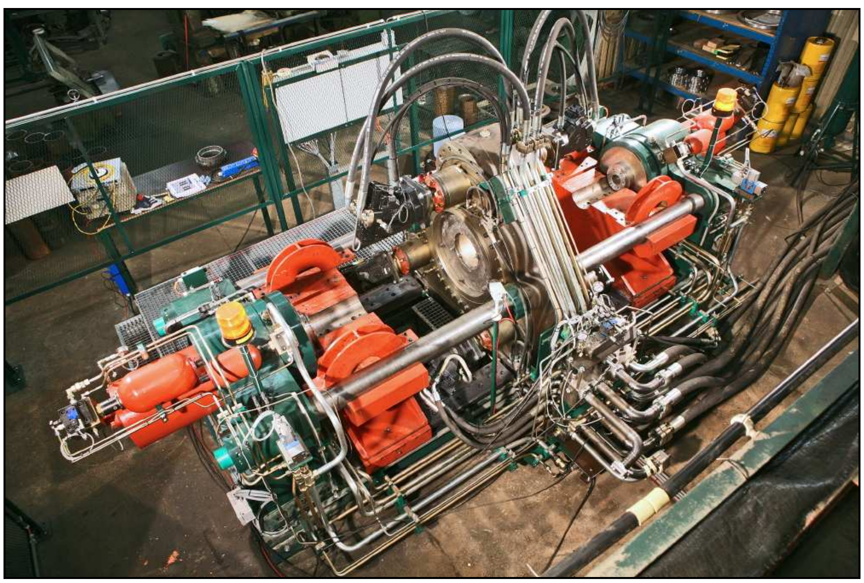

Figure 17 : *Large-scale test set-up*

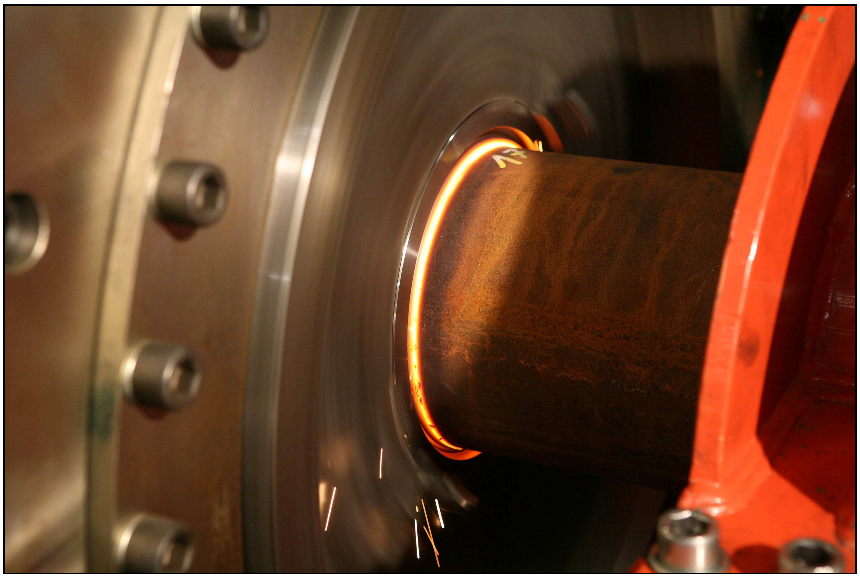

Figure 18 : *Welding experiment*

Weldability of L450QB (API-5L X65)

For investigation of the use of the new welding process for joining high-strength micro-alloyed pipeline steels, exploratory welding trials were performed with the quenched and tempered micro-alloyed high-strength pipeline steel L450QB [23], [24], [25], [26], [27].

The weld quality was assessed based on metallographic examinations, tensile, bending and Charpy impact testing.

The tensile test specimens fractured in the pipe base material, at a tensile strength equal to the pipe base material tensile strength. All bending test specimens could be bent to an angle of 180° without fracture.

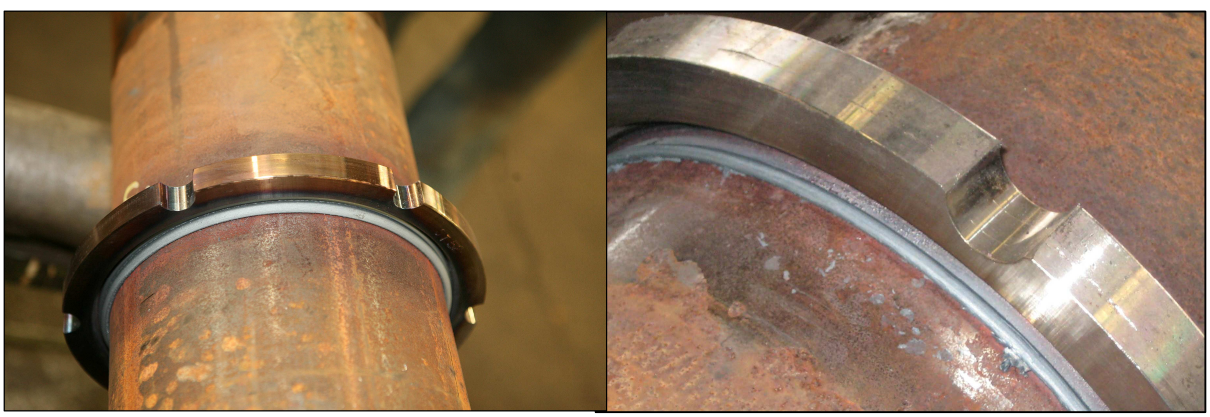

Figure 19 : *Weld of 8 inch pipes (O.D. : 219 mm) in the as-welded condition*

For each weld 3 sets of at least 6 Charpy impact tests were carried out. Three types of test specimens were used, based on the position of the notch (in the middle of the welding ring, or at the left or at the right weld interface). In EN 12732 an average impact energy of 40 J is required, with the individual values not lower than 30 J for steel grades with a specified minimum yield stress higher than 360 MPa. The testing temperature is equal to -20℃.

The impact toughness of the investigated welds is shown in Figure 20 as a function of the total heat input. At the weld interface, the impact toughness is high for the lowest heat input. The impact toughness decreases for a higher heat input. The impact toughness measured in the middle of the welding ring is always high and not dependent on the heat input.

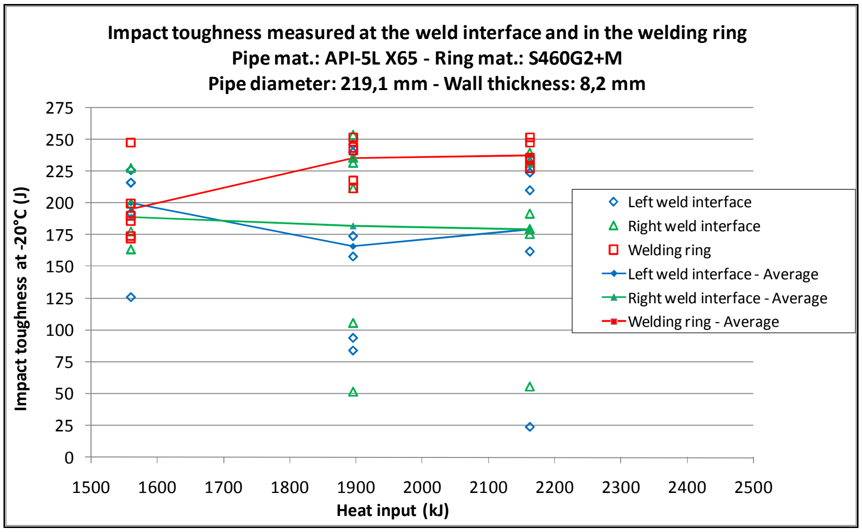

Figure 20 : *Charpy impact toughness as function of the heat input*

In the pipe HAZ of all welds, the hardness decreases slightly below the base material hardness value (193 HV1), at 2 to 6 mm from the weld interface (Figure 21). Also in the welding ring HAZ, softening is observed (hardness ring base material: 196 HV1). The width of the softened zone decreases for a lower heat input. Weld 3, executed with the lowest heat input, contains the smallest softened zone. Also the hardness decrease is minimal for this weld. The decrease of the hardness is however not detrimental to the weld strength; since all tensile test specimens broke outside of the weld zone.

The weldability of the pipe material L450QB was thus successfully demonstrated, which opens promising perspectives for the weldability of other and higher-strength pipeline steels.

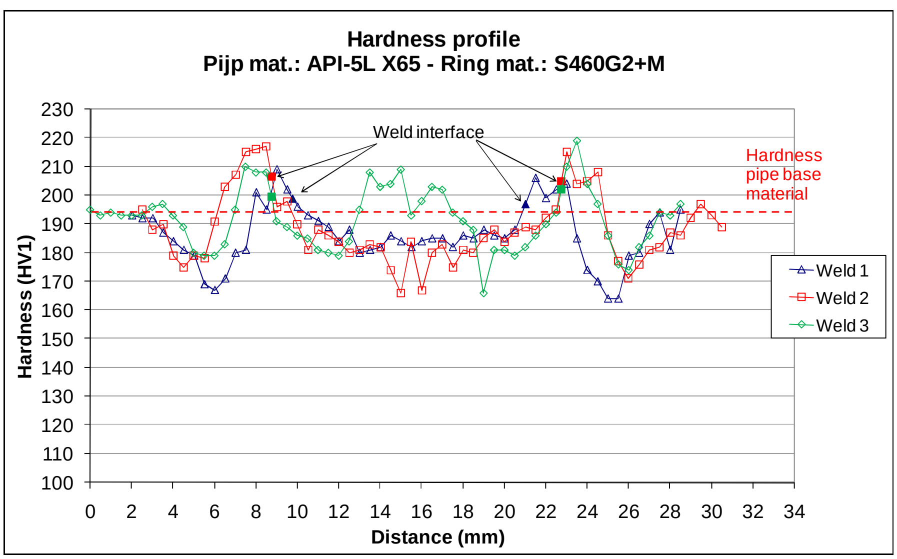

Figure 21 : *Hardness profile of the investigated welds*

4. Implementation of the process

A design was made of a large-scale operational field machine with capabilities for welding steel pipes with a diameter of 220 up to 504 mm (Figure 22 and Figure 23). Various technical aspects of a field operation were investigated, such as the necessary drive torque, power capacity, clamping methods for coated pipes, axial forces between welding ring and pipe, fixture of the welding ring, internal clamping, removal of welding flashes, forging forces, etc.
In addition, a first concept was designed for flash removal after the weld cycle (Figure 24).

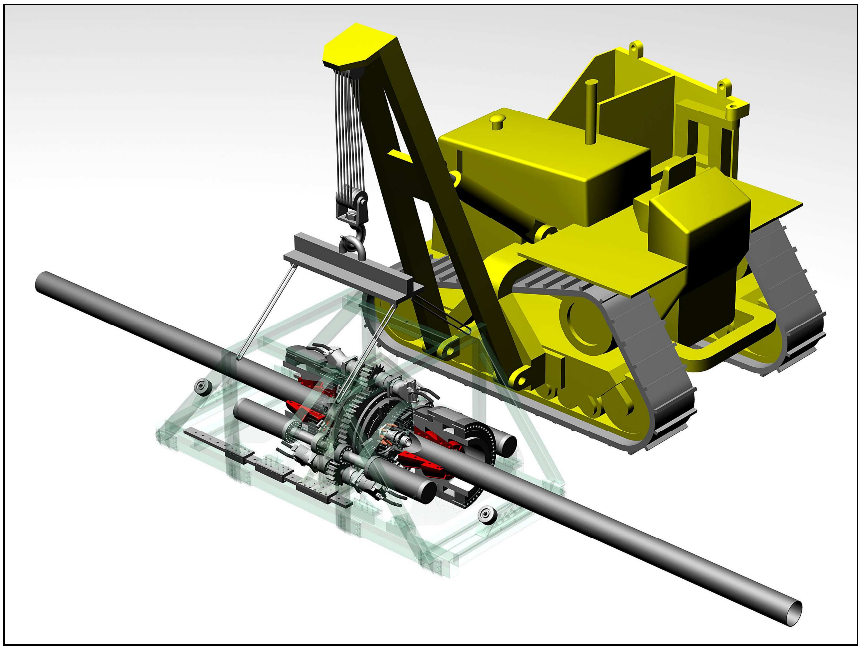

Figure 22 : *Design of a large-scale field machine*

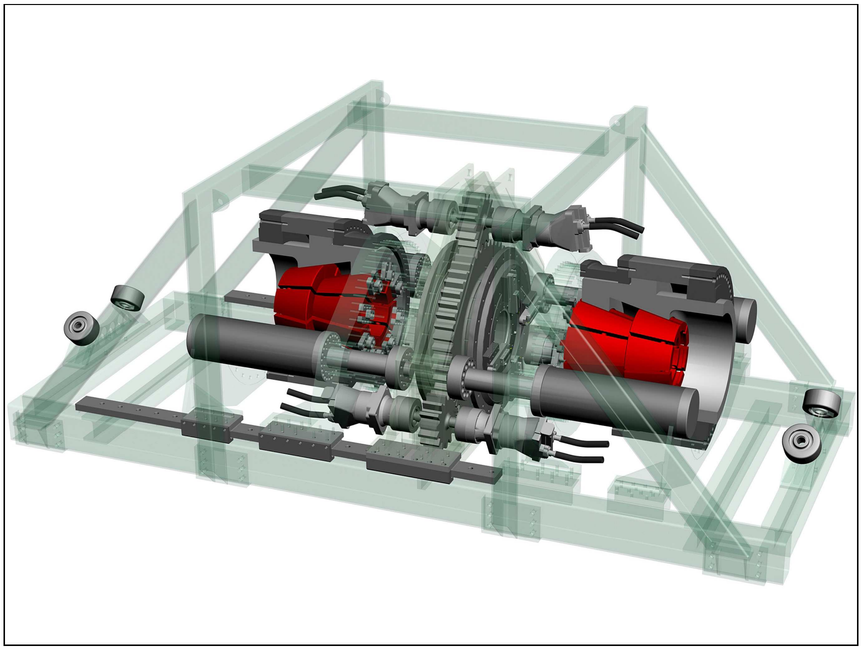

Figure 23 : *Design of a large-scale field machine*

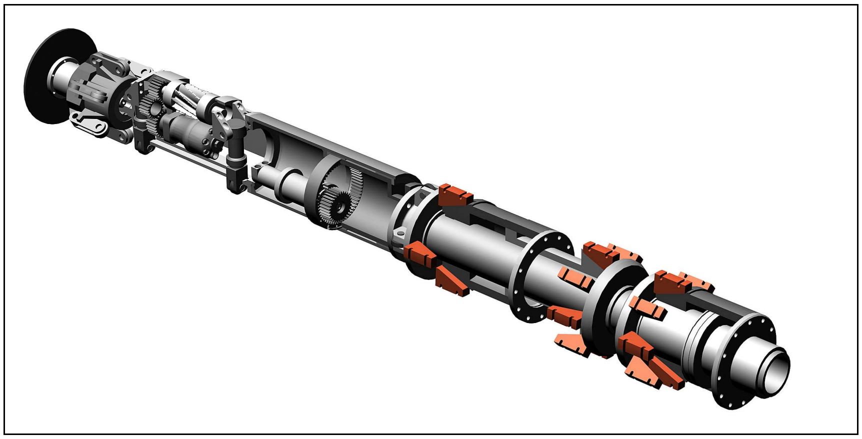

Figure 24 : *Design of a line-up clamp and flash removal device*

Initial steps were taken in the area of welding process qualification, such as the design and construction of a large-scale tensile test installation at UGent (Figure 25).

Figure 25 : *Large-scale tensile test set-up*

To examine pipe joints in pipes with a diameter up to 504 mm, a new full-scale resonant bending fatigue test set-up was developed at Laboratory Soete (Figure 26). In this set-up, the pipe with a joint is excitated by a drive unit with eccentric masses. The central section of the pipe is subjected to the highest bending loads during fatigue testing. The specifications are :

- Pipe diameter : 168 to 504 mm (6" to 20")
- Pipe wall thickness : 5 to 40 mm
- Pipe length : 4 to 6 m
- Max. deflection amplitude : 38 mm
- Frequency : 20 to 40 Hz

Figure 26 : *Large-scale fatigue test set-up*

5. Conclusions

The feasibility of the FRIEX welding process has been successfully demonstrated. The study of this new variant of the friction welding process shows that the process is suitable for joining pipes. Using the small and medium-scaled experimental test set-ups, high quality welds could be produced for pipes in the pipeline steels L290NB and L360NB with a maximum outer diameter of 141 mm. Suitable welding ring materials could be defined for welding these pipe materials.

An extensive knowledge has been obtained concerning the heat distribution, heat flow, plasticity and material behaviour of the parts to be joined. The use of finite element simulations proved to be a very helpful tool for a better understanding of the process, orientation of experiments, prediction of the process parameters and the machine working range and for designing and evaluating the welding ring design.

Using a large-scale test set-up, the weldability of the micro-alloyed high-strength pipeline steel L450QB has been experimentally investigated. It was found that the Friex welding process is suitable for joining this material.

The implementation of the process has also been studied : a design has been made of a large-scale operational field machine with capabilities for welding steel pipes with a diameter of 220 up to 504 mm. Various technical aspects of a field operation were investigated, such as the necessary drive torque, power capacity, clamping methods for coated pipes, axial forces between welding ring and pipe, fixture of the welding ring, internal clamping, removal of welding flashes, forging forces, etc.

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