FINITE ELEMENT MODELLING OF UOE PIPE MANUFACTURING PROCESS

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1. ABSTRACT

A significant number of large-diameter-thickness pipes used in offshore applications are manufactured by cold-forming plates through the UOE process, consisting of four sequential forming steps. In this study the UOE forming process is modeled numerically through the application of a non-linear finite element code. Special emphasis is given on the effects of the last step of the manufacturing process (expansion) on the value of initial out-of-roundness and thickness variation.

2. INTRODUCTION

Oil and gas pipelines are widely used in transporting hydrocarbon energy resources in the most effective and safe way. Pipelines usually require a significant initial investment cost for their manufacturing, but during their service life (30-40 years) they have relatively low maintenance and operation costs; they are also characterized by a small number of accidents. In the recent years a considerable number of pipelines has been constructed or are in the design stage. In some cases, a long segment of the pipeline is underwater.

The mechanical design of offshore pipelines follows a the limit-state design approach. Following this concept one should design the pipeline against all possible failure modes. Buckling under external pressure constitutes a fundamental limit state for the design of offshore pipelines. The external pressure is due to the significant water depth, the corresponding failure is commonly mentioned as “collapse”, associated with a flattened “dog-bone” shape of the pipe cross-section [1], [2].

The forming process is an important parameter that determines the level of imperfections and residual stresses in a pipe, and therefore, it should be taken into consideration for the prediction of the ultimate external pressure [3], [4], [5]. In the present paper, the UOE cold-forming manufacturing process is examined in terms of its effects on the mechanical behavior of offshore pipelines. Recent studies have highlighted the influence of this manufacturing process on the value of maximum external pressure. In the present study, the UOE forming process for a 609.6 mm (24-inch) diameter pipeline, candidate for deep-water applications, is simulated using nonlinear finite elements, so that initial imperfections and residual stresses at the end of the manufacturing process are predicted. The present simulation may be employed as a useful tool for optimizing the UOE manufacturing process.

3. DESCRIPTION OF THE UOE MANUFACTURING PROCESS

A popular manufacturing method for large diameter pipes used in subsea consists of cold-forming long plates through the UOE process. The name UOE stems from the initials of the last three of these mechanical steps (U-ing, O-ing, E-xpansion). The UOE steel pipe forming process was originally proposed for buried pipelines and more recently extended to subsea pipelines. The process is realized in four sequential mechanical steps:

- Crimping the plate edges
- U-ing phase, the pipe is formed into a U-shape
- O-ing phase, the pipe is pressed into an almost circular shape and both ends of the plate are welded and
- Expansion phase, the application of internal pressure for improving the circularity of the pipe.

The first forming step involves crimping of the plate edges at both sides into circular arcs of about one radius width. This is achieved by pressing the ends between two shaped dies as shown in Fig. 1. Because of the large forces required in this step, the forming is executed in steps. The length of the plate varies between one and four times the pipe diameter, depending on the pipe thickness. Each production factory is equipped with appropriate sets of dies in order to adjust the forming process to the desired thickness and diameter of the pipes required. In particular, for a given pipe the dies with the most appropriate inner and outer radii (ρ_{CRi} and ρ_{CRo}) are selected, as depicted in Fig. 1(b). The relative horizontal positions of the dies can be adjusted as desired. The width of the steel plate to be crimped is defined from the horizontal position of the dies (L_{CR}) and depends on the plate thickness and the maximum load capacity F_{CR} of the press (Fig. 1(b)).

Upon completion of this step, the steel plate proceeds to the U-ing phase (Fig. 2), performed in two stages. During the first stage, the U-punch moves downwards and bends the entire plate through a three-point bending process. The U-punch radius is selected so that the lower half of the steel plate acquires a radius close to the desired pipe radius at the end of the step. The U-punch stops moving when the plate touches the anvil. The U-punch is then held in place, and the side rollers move inwards approaching one another. The horizontal position (h_r) where the side rollers are activated and the distance (δ_r) they cover are selected so that the final form of the plate to be close to a “U” shape and the two branches of the plate are nearly vertically positioned.

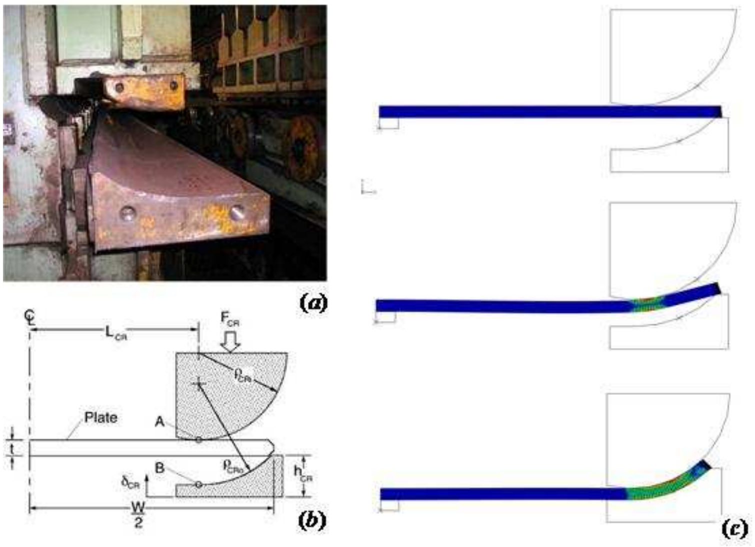

Fig. 1 The crimping phase, where the lower die moves upwards; (a) Representative phase of the forming process, (b) Schematic representation of crimping press and (c) Present finite element numerical simulation.

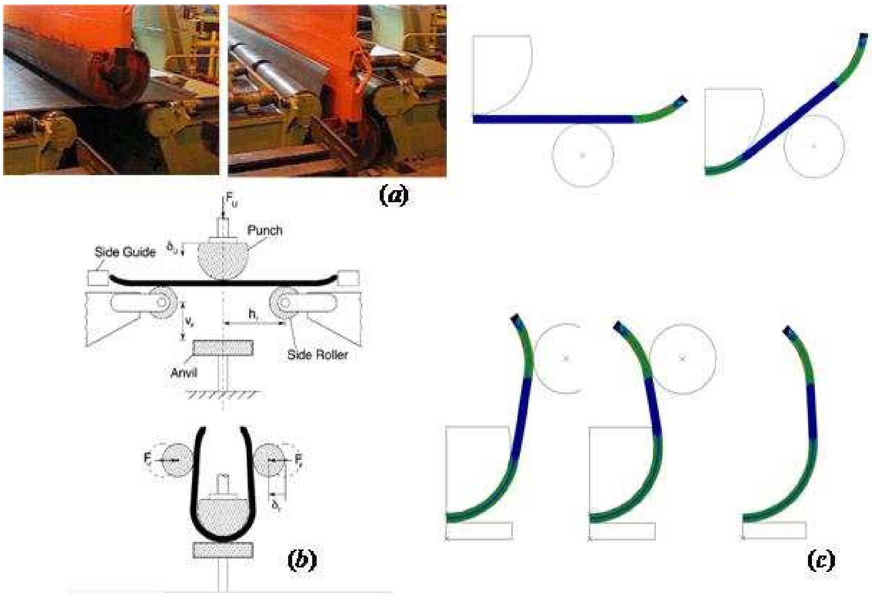

Fig. 2 The U-ing phase is realized with the displacement of the U-punch, the displacement of the side rollers and the unloading of the steel; (α) Representative picture of U-ing, (b) Schematic representation of U-ing process, (c) Present numerical simulation.

Subsequently the plate is conveyed into the O-ing phase, realized by two semi-circular rigid dies with radius ρ_0. The upper die is pushed downwards, forcing the plate to acquire a circular form (Fig. 3). The forming ends with the application of the O-die. After the O-ing phase, the two edges of the pipe, already beveled from the initial phase, are welded together with SAW (Submerged Arc Welding), first on the inside and then on the outside (Fig. 4(a)). At this stage, extensive ultrasonic checks are also performed to detect any weld defects prior to the pipe expansion.

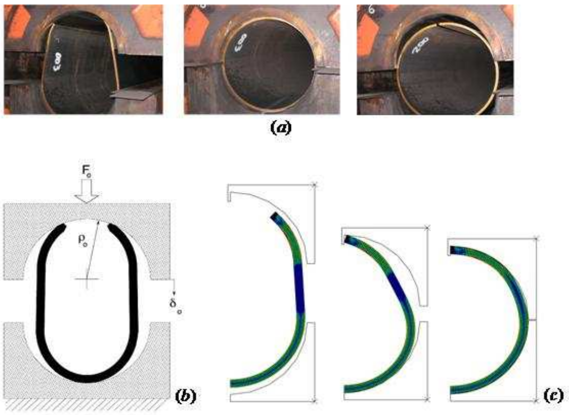

Fig 3 The O-ing phase where the semi-circular die moves downwards until it touches the other die to facilitate the welding of the two beveled edges; (a) Representative sketch of this phase, (b) Schematic representation of O-press and (c) Present numerical simulation.

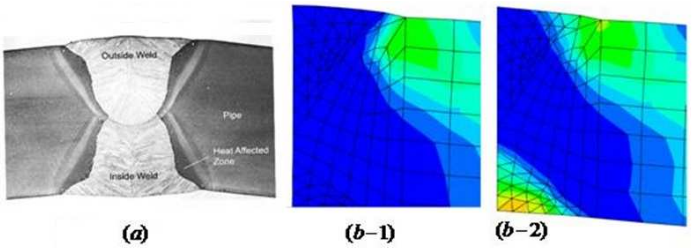

Fig. 4 (a) Welding metallography at the top edge of the plate and present numerical simulation of the weld procedure: (b-1) prior the welding and (b-2) after the welding.

The final step of the forming process is pipe expansion, necessary to control the shape of the pipe cross-section, so that welding between adjacent pipe segments is performed without significant misalignment. Furthermore, the expansion improves the roundness of the pipe giving it its final size, improving its structural performance in terms of ultimate buckling pressure. The step is realized using a mandrel, inserted in the pipe (Fig. 5), and usually consists of 8, 10 or 12 segments. In this model, 8 segments were assumed in the circumference of the pipe, selected so that their radii (ρ_E) to be almost equal to the internal radius of the pipe. The mandrel is hydraulically actuated and all the segments move outwards radially. The distance covered by the segments depends on the plate thickness and constitutes a basic parameter of the manufacturing process.

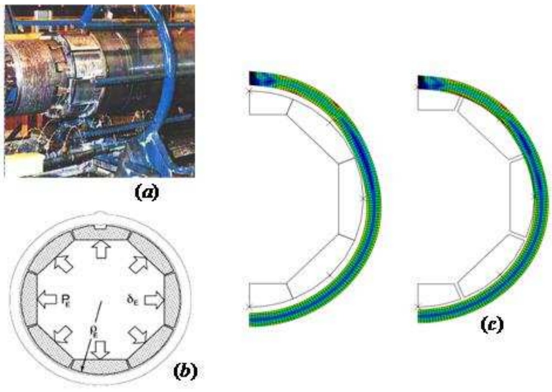

Fig. 5 Pipe expansion (a) Representative picture of the expansion phase, (b) Schematic representation of expansion, (c) Results from the present numerical simulation with an 8-part mandrel.

5. NUMERICAL RESULTS

The developed numerical model described in the previous paragraph is utilized to study a pipe of 609.6 mm external nominal diameter and 32.3 mm wall thickness. The material of the plate was assumed to have Young modulus E = 210 GPa, yield stress σ_y = 448.5 MPa (X65 steel grade) and Poisson ratio v = 0.3. The plasticity model adopted for this analysis is the von Mises flow theory with isotropic hardening. All the forming parameters and the characteristics considered are reported in Table 1.

	Symbol	**Description**	**Value**
Plate	t	Plate thickness (mm)	32.33
	W	Plate width (mm)	1803
	X	Steel grade (MPa)	448.5
Crimping	ρ_{CRi}	Internal crimping radius (mm)	265.4
	ρ_{CRo}	External crimping radius (mm)	298.5
	δ_{CR}	Final distance of the 2 dies (mm)	0.5
	L_{CR}	Horizontal distance of the dies (mm)	676.7
	h_{CR}	Height of the external crimping die (mm)	150
U-ing	ρ_U	U-Punch radius (mm)	246.4
	δ_U	Distance covered by the U-Punch (mm)	724
	δ_r	Distance covered by the Roller (mm)	102
	h_r	Horizontal Roller position (mm)	457
	υ_r	Vertical position of the Anvil (mm)	724
O-ing	ρ_O	Radius of the semi-circular dies (mm)	303.8
	δ_O	Distance covered by the O-die (mm)	218.55
Expansion	ρ_E	Mandrel radius (mm)	260
	δ_E	Expansion value (mm)	11
	N_E	Mandrel segments	8

Table 1. Characteristics of the UOE numerical simulation.

The basic parameter examined is the total expansion, $u_{Expansion}$, at the final stage of the forming process. Particularly, different expansion values are examined ranging from $u_{Expansion}$ = 8.2 mm (first contact with the plate's interior edge in the particular model) to $u_{Expansion}$ = 15 mm beyond which severe plastic deformations of the pipe take place. For that reason, the auxilliary parameter δ_E is defined as follows:

$$\delta_E = u_{Expansion} - \Delta_0 \tag{1}$$

where Δ_0 = 8.2 mm is the minimum $u_{Expansion}$ value in our case and $u_{Expansion}$ is the total expansion value. Moreover, the ovalization parameter ov_0 is defined:

$$ov_0 = \frac{|D_1 - D_2|}{D_1 + D_2} \tag{2}$$

where D_1 and D_2 are the horizontal and vertical outer diameters respectively, measured at the end of the O-phase just after the unloading of the pipe. These two diameters are different since the pipe is not of perfect cyclic shape. Therefore the ovalization parameter ov_0 is a measure of the initial pipe geometric imperfection. In addition, the mean thickness of the pipe, t_m, is defined using thickness measurements at three different locations:

$$t_m = \frac{t_1 + t_2 + t_3}{3} \tag{3}$$

In the above expression t_1 is the pipe thickness on the top part of the pipe cross-section (near the weld), t_2 is the pipe thickness on the middle height of the pipe cross-section and t_3 is the pipe thickness on its lower part, as shown in Fig. 6. Finally, a non dimensional imperfection parameter ΔT is introduced, which expresses the mean variation of the circumferential pipe-wall thickness:

$$\Delta T = \frac{t_{\max} - t_{\min}}{t_m} \tag{4}$$

where t_{max} refers to the maximum value and t_{min} refers to the minimum value of the pipe-wall thickness derived from t_1, t_2, t_3.

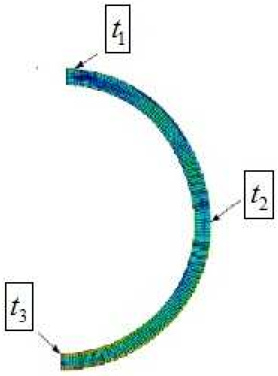

Fig. 6 Part of the pipe ring where t_1, t_2 and t_3 are defined.

The effect of the additional expansion δ_E is shown in Fig. 7. It is observed that the increase of the total expansion leads to the minimization of the pipe out-of-roundness. Moreover, Fig. 8 shows the effect of the expansion in the pipe-wall thickness. By examining these diagrams it is concluded that there is an optimum expansion value δ_E for which there is minimization of ovalization of the pipe cross-section and minimum pipe-wall thickness variation. In the present case, this optimum expansion value is equal to about 4 mm.

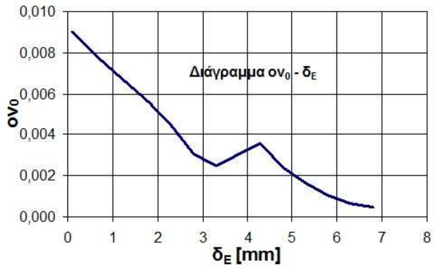

Fig. 7 Ovalization parameter ov_0 *versus additional expansion.*

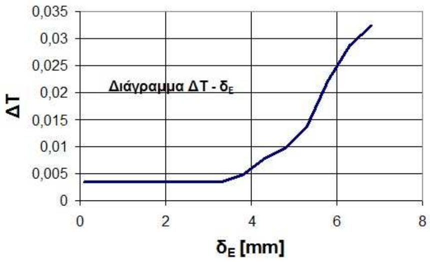

Fig. 8 Parameter ΔT *versus additional expansion.*

6. CONCLUSIONS

The present study examines the UOE pipe forming process with the use of robust computational tools. The study is aimed at the computation of the initial imperfections of the formed pipe and afterwards the pipe's capacity against external pressure application. It is observed that the increase of the total expansion leads to the minimization of the pipe out-of-roundness. On the other hand, significant expansion may lead to undesired pipe-wall thickness variations. The simulation of UOE forming process allows for the reliable estimate of optimum expansion.

7. REFERENCES

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ΠΡΟΣΟΜΟΙΩΣΗ ΤΗΣ ΚΑΤΕΡΓΑΣΙΑΣ ΔΙΑΜΟΡΦΩΣΗΣ ΣΩΛΗΝΩΝ UOE ΜΕ ΠΕΠΕΡΑΣΜΕΝΑ ΣΤΟΙΧΕΙΑ

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ΠΕΡΙΛΗΨΗ

Οι αγωγοί πετρελαίου και φυσικού αερίου αποτελούν ένα σημαντικό μέσο συλλογής και μεταφοράς ενεργειακών πόρων. Απαιτούν ένα σημαντικό αρχικό κόστος επένδυσης, αλλά στην διάρκεια ζωής τους απαιτούν σχετικά μικρό κόστος συντήρησης και λειτουργίας. Σε μερικές περιπτώσεις, ένας αγωγός ή ένα τμήμα του είναι υποθαλάσσιο.

Ένας σημαντικός αριθμός σωλήνων μεγάλης διαμέτρου και πάχους, που χρησιμοποιούνται για την κατασκευή υποθαλάσσιων αγωγών πετρελαίου και φυσικού αερίου, κατασκευάζονται με την εν ψυχρώ κατεργασία διαμόρφωσης τύπου UOE. Η κατεργασία αυτή αποτελείται από τέσσερα διαδοχικά μηχανικά βήματα. Στην παρούσα εργασία η εν λόγω κατεργασία προσομοιώνεται αριθμητικά. Η προσομοίωση επιτυγχάνεται με την εφαρμογή ενός μη-γραμμικού κώδικα πεπερασμένων στοιχείων και έχει σαν κύριο στόχο την μελέτη της επίδρασης της εφαρμοζόμενης διαστολής στα γεωμετρικά χαρακτηριστικά του διαμορφωμένου σωλήνα. Πιο συγκεκριμένα, παρατηρείται πως αύξηση της συνολικής διαστολής οδηγεί σε ελαχιστοποίηση της απόκλισης της διατομής του σωλήνα από την τέλεια κυκλική γεωμετρία. Εντούτοις, μεγάλες τιμές της διαστολής συνεπάγονται ανεπιθύμητες μεταβολές του πάχους του διαμορφωμένου σωλήνα. Σύγκριση των αποτελεσμάτων επιτρέπει την επιλογή της βέλτιστης τιμής για τη διαστολή.