UOE PIPE STRAINS MEASUREMENT DURING MANUFACTURING PROCESS USING DIGITAL IMAGE CORRELATION

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ABSTRACT

UOE pipe manufacturing process influence directly on pipeline resilience and operation capacity. At present, most spreaded pipe manufacturing method is UOE. This kind of manufacturing process is based on cold forming principle. To avoid appearance of unwanted effects, the need to know the level of strains resulted after every techological step appeared. For this case a manufacturing process by using special designed equipment is simulated. The experimental simulation presented in this paper is performed for L 415MB (X60) steel plate with 7,9 mm thickness and a width of 1250 mm. As a result a DN 400 (16 inch) pipe is obtained. Manufacturing process is monitored by Digital 3D Image Correlation System Q-400 and the priciple of operation is based on Digital Image Correlation.

Keywords: *UOE pipe, strains, residuals strains, digital image correlation, testing machine.*

1. INTRODUCTION

UOE double submerged arc welded pipe manufacturing process involves plastic strains appearance. International abbreviation UOE (Figure 1) represents principal mechanical steps, so U (Figure1b) – represents when plate is formed into U - shape, O (Figure1c) – represents the moment when U shape is pressed into circular shape and final step E (Figure1d) – represents expanding operation that means obtaining standard size of pipe, but always, first step is edge crimping operation (Figure1a) that means edge preparing for weld seam execution, i.e. plate edges crimping into circular shape.

Through optical non-destructive testing method - digital image correlation, after each step, strains have been measured. Underlines the fact that measurments were performed for 3 strips (ensuring the quality of the measured results) and one of them is presented.

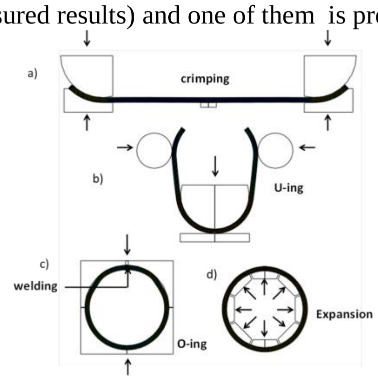

Figure 1 UOE forming steps

Experimental simulation monitoring is performed by using Digital 3D Image Correlation System Q-400 (referred to hereinafter as DIC) [3]. This system is an optical measuring device and uses 2 cameras for non-contact and three-dimensional measurement of strains.

According to [9], manufacturing process is performed by using special designed equipment (Figure 2).

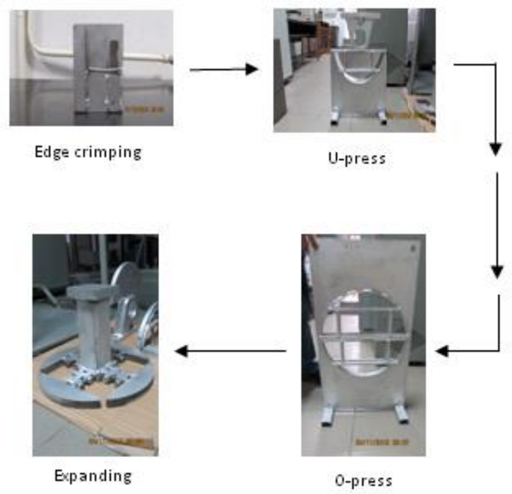

Figure 2 UOE process equipment

It must be mentioned that intended plates are cutted by using water jet cutting machine, to avoid apearance of unwanted strains.

2. EDGE CRIMPING

Starting an experimental simulation consists in prepairing, mounting and calibration of required equipment. Below is a list of implicated equipment:

-universal testing machine ZDM 100 [10];
-Digital 3D Image Correlation System Q-400, [3];
-manufactured equipment for experimental simulation [9];

Figure 3 Mounting and equipment calibration

After equipment mounting, the next and very important step represents calibration. The purpose of calibriation is a grayscale correlation of the one pixel from the modified image and original image [5]. Greyscale is presented in figure 4, and for correlation creation, the surface of the table was specially treated as shown in figure 5.

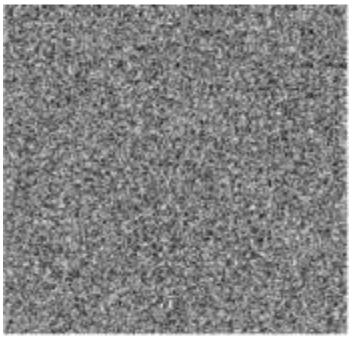

Figure 4 Greyscale

Figure 5 Surface prepared for measurment

Certainity and accuracy of calibration is shown in figure 6, where position and surface of the strip are presented.

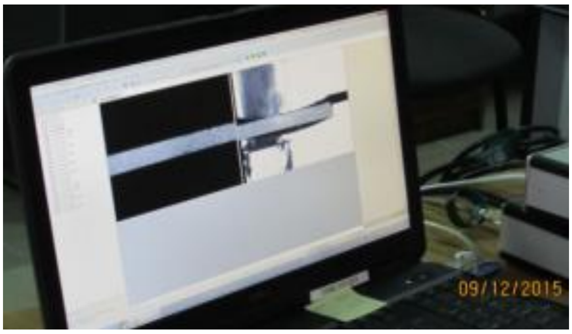

Figure 6 DIC sistem calibration

After all preparations, simulation is starting with edge crimping. As shown in figure 7, die is positioned on the testing machine table and strip under punch. Testing machine press function is activated and edge crimping process is started.

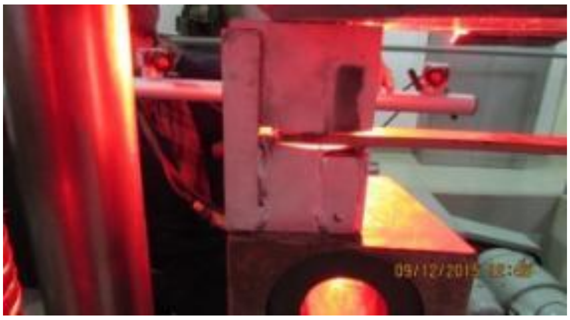

Figure **7** First step – edge crimping

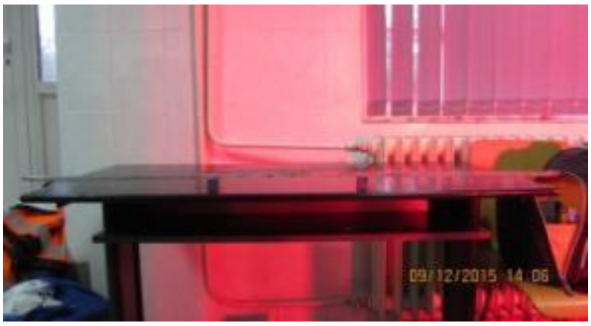

Figure 8. Obtained edges

Obtained result is presented in figure 8. The DIC measurment results are presented in figure 9. After DIC inspection, as shown in figure 8, highest value of strains is in crossing area, from circular shape to plane shape.

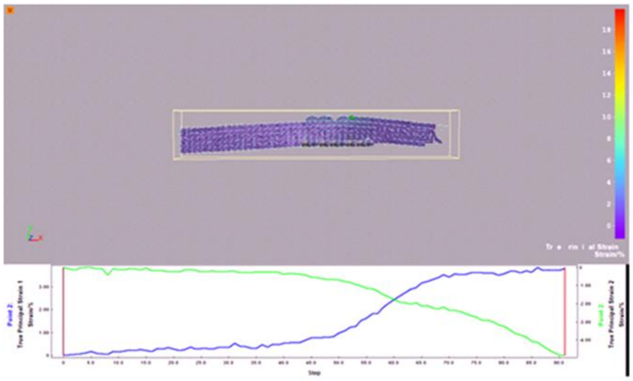

Figure 9 Edge crimping monitoring
Blue curve – plastic strain 1
Green curve – plastic strain 2

A stage was divided into 91 steps. After edge crimping simulation, next values of plastic strains were obtained: Maximum values: plastic strain 1 - $\varepsilon_{Jmax}^{1} = 2,73\%$, and plastic strain 2 - $\varepsilon_{\mathrm{Jmax}}^{2} = -2,39\%$ (Figure 9). Residual values: plastic strain 1 - $\varepsilon_{Jres}^{1} = 2,66\%$, and plastic strain 2 $\varepsilon_{\mathrm{Jres}}^{2} = -2,33\%$.

3. „U"SHAPE FORMING

Next step represents U shape forming. For this stage, just punch and die for U shape are changed, as shown in figure 10. DIC is on position, but is calibrated by height. Strip position toward the die is symmetric. General view of the die and strip is presented in figure 12.

Figure 10 Equipment mounting for „U"forming

Figure 11 „U"shape forming process beginning

Figure 12 „U"shape forming process beginning

After all arrangements simulation is starting.

Vertical movement of the testing machine crosshead in conection with U - punch bends entire plate till the moment when strip is formed in U shape, as shown in figure 13.

Figure 13 Strip symmetrical position towards die

Figure 14 Strip formed in U shape

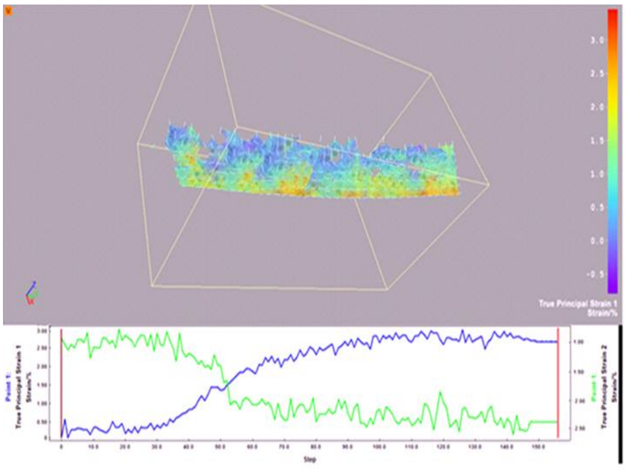

Figure 15 „U"shape forming monitoring
Blue curve – plastic strain 1
Green curve – plastic strain 2

After U shape forming simulation next values of plastic strains were obtained: Maximum values: plastic strain 1 - $\varepsilon^1_{Umax} = 3{,}2\%$, , and plastic strain 2 - $\varepsilon^2_{Umax} = -2{,}6\%$ (Figure 14). Residual values: plastic strain 1 - $\varepsilon^1_{Ures} = 2{,}62\%$, and plastic strain 2 - $\varepsilon^2_{Ures} = -2{,}42\%$.

4. „O" SHAPE FORMING

„O" shape forming operation is the last step where bending is used. In this moment the plate is pressed into circular shape and both ends are welded.

Figure 16 „O”shape forming process running

During pipe circumference monitoring for 3 strips with same material, 2 areas with highest values of deformation have resulted, as presented in figure 17. It must be mentioned that, areas 1 and 2 according to pipe symmetry, have the opposite position on pipe circumference. In figure 18 is presented the measurement result for area 1 (position – 110 mm from welding seam on pipe circumference) and respectively in figure 19 is presented the result for area 2 (position – 214 mm from welding seam on pipe circumference).

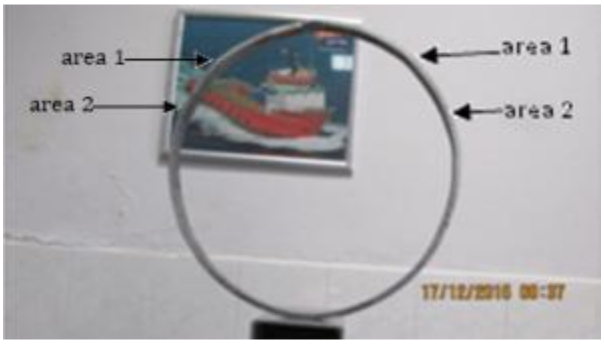

Figure 17 Obtained result after „O”shape forming

Plastic strains evolution for „O” shape forming process is shown in figure 18.

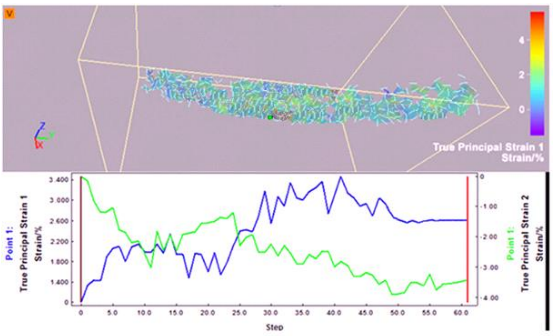

Figure 18 „O” shape forming monitoring for area 1
Blue curve – plastic strain 1
Green curve – plastic strain 2

After „O” shape forming simulation for area 1, the next values of plastic strains resulted: Maximum values: plastic strain 1 - $\varepsilon^1_{0max} = 3{,}4\%$, and plastic strain 2 - $\varepsilon^2_{0max} = -3{,}7\%$ (Figure 18). Residual values: plastic strain 1 - $\varepsilon^1_{0res} = 2{,}61\%$, and plastic strain 2 - $\varepsilon^2_{0res} = -3{,}33\%$.

The following are presented measurements for area 2 (Figure 19).

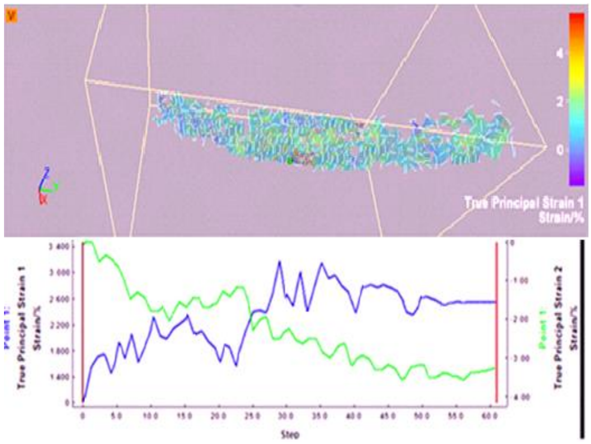

Figure 19 „O” shape forming monitoring for area 2
Blue curve – plastic strain 1
Green curve – plastic strain 2

After „O” shape forming simulation for area 2 the next values of plastic strains resulted: Maximum values: plastic strain 1 - $\varepsilon^1_{0max} = 3{,}51\%$, and plastic strain 2 - $\varepsilon^2_{0max} = -3{,}49\ \%$ (Figure 19). Residual values: plastic strain 1 - $\varepsilon^1_{0res} = 2{,}69\ \%$, and plastic strain 2 - $\varepsilon^2_{0res} = -3{,}28\ \%$.

The first 3 main steps of manufacturing process were based on rectangular plate bending. Follows last and most important step namely expanding operation. Expanding principle is based on the next physical model: thin walled cylinder loaded by internal pressure.

5. EXPANDING

In reality, pipe is loaded by using mechanical expander [7], but for simulation especially, manufactured expander will be used for DN 400 pipe expanding. The principal is the following: mechanical expander produces radial oriented internal pressure for pipe wall plastic deformation. Expander mounting is shown in figure 20.

Being based on API 5L standards [8] the pipe is to be expanded to a ratio of - greater than 0.3% and less than or equal to 1,5 % . In this case, pipe will be expanded to a ratio of 0.8%.

Figure 20 Mechanical expander mounting

For expanding ratio on testing machine, table is made a mark for displacement equal 3,25 mm corresponding to value of 0,8%.

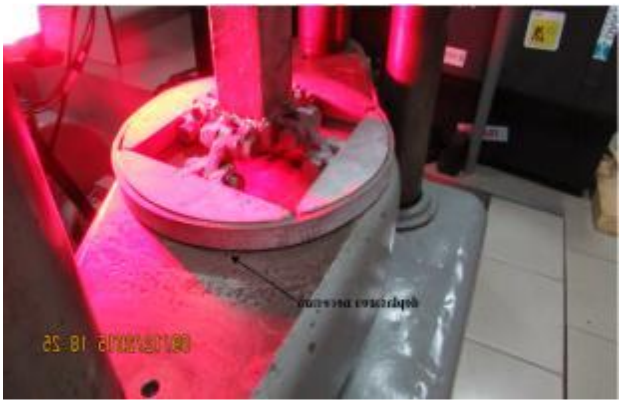

Figure 21 Expanding process runing

During expanding operation areas resulted from O-press operation were monitered. For area 1, in figure 22 the measurement result is presented.

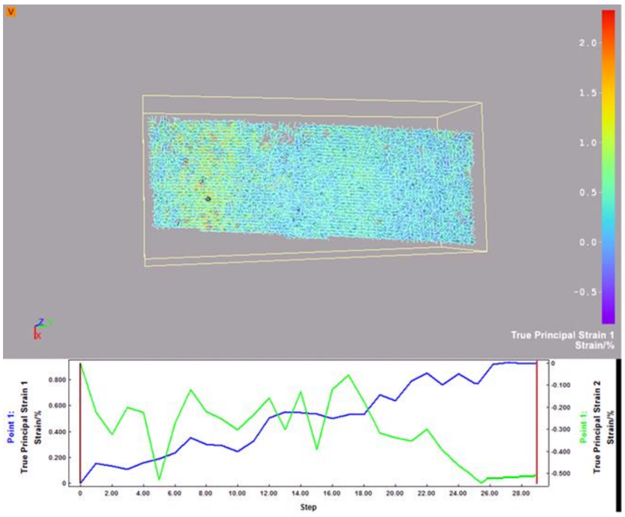

Figure 22 Expanding process monitoring – area 1
Blue curve – plastic strain 1
Green curve – plastic strain 2

After expanding simulation, next values of plastic strains were obtained: Maximum values: plastic strain 1 - $\varepsilon^1_{Emax} = 0{,}93\%$, and plastic strain 2 - $\varepsilon^2_{Emax} = -0{,}56\%$ (Figure 22). Residual values: plastic strain 1 - $\varepsilon^1_{Eres} = 0{,}88\%$, and plastic strain 2 - $\varepsilon^2_{Eres} = -0{,}53\%$. It should be noted that, residual strains resulted after expanding, represent the sum of strains resulted after circular shape obtaining and expanding operation, as shown in below relations:

$$\varepsilon^1_{Eres} = 3{,}3\% + 0{,}88\% = 4{,}23\% \quad (1)$$

$$\varepsilon^2_{Eres} = 2{,}6\% + 0{,}53\% = -3{,}13\%$$

Monitoring results for area 2 are presented in figure 23.

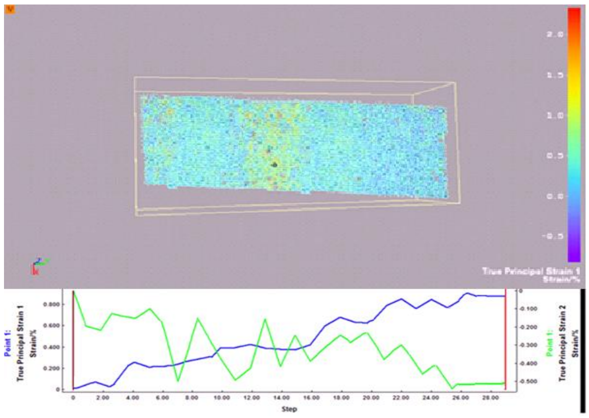

Figure 23 Expanding process monitoring – area 2
Blue curve – plastic strain 1
Green curve – plastic strain 2

Measurement results are presented below.

Maximum values: plastic strain 1 - $\varepsilon^1_{Emax} = 0{,}96\ \%$, and plastic strain 2 - $\varepsilon^2_{Emax} = -0{,}52\%$ (Figure 23). Residual values: plastic strain 1 - $\varepsilon^1_{Eres} = 0{,}91\ \%$, and plastic strain 2 - $\varepsilon^2_{Eres} = -0{,}44\%$. It should be noted that, residual strains resulted after expanding, represent the sum of strains resulted after circular shape obtaining and expanding operation, as shown in below relations:

$$\varepsilon^1_{Eres} = 3{,}28\ \% + 0{,}91\% = 4{,}19\ \% \quad (2)$$

$$\varepsilon^2_{Eres} = 2{,}69\ \% + 0{,}45\% = -3{,}14\ \%$$

After expanding operation, resulted pipe is presented in figure 24.

Figure 24 Obtained result after expanding

6. CONCLUSION

The strains in pipe samples manufactured by UOE method were measured using optical device - Digital 3D Image Correlation System Q-400. Residual strains values, resulted after each technological step are presented in table 1.

Based on experimental simulation, the level of resulted strains is influenced by manufacturing process and their distribution is unevenly. From this reason strains concentration areas appeared as presented in figure 17. These concentration areas directly influence stress and strain state because every pipeline system during its design life is subjected to different cyclical and dynamical loads. Overlapping phenomenon of the residual stresses resulted from the strain concentration areas with stresses resulted after cyclical and dynamic loads, may lead to unwanted effects, like stress corrosion pipe cracking.

Detection of the strain concentration areas and strain measurement can be useful for stress analysed software systems to keep the stresses within the admissible limits and for manufacturers to improve UOE process.

Table 1 Residual plastic strains values

Plastic strains		Experimental study $[10^{-3}]\frac{m}{m}$
J	ε^1_{Jres}	2.66
	ε^2_{Jres}	-2.33
U	ε^1_{Ures}	2.62
	ε^2_{Ures}	-2.42
O	ε^1_{Ores}	2.69
	ε^2_{Ores}	-3.28
E	ε^1_{Eres}	4.23
	ε^2_{Eres}	-3.13

7. REFERENCES

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