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INCREASE OF EFFICIENCY OF PIPE ENDS UPSETTING TECHNOLOGY BY RESEARCH ON METAL FORMING

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ABSTRACT

Oil country tubular goods (OCTG) are widely used in oil and gas industry. In order to increase joint efficiency of the oil country tubular goods, the process for upsetting their ends is applied. However, the weakness of this upsetting technology is a frequent formation of defects on the inner surface of the final product. These imperfections are surface breakings that reduce the effective pipe wall thickness; they are detected close to the upset ends of the pipe. Computer simulation and full-scale experiment were used to study this defect nucleation. According to this research, the occurrence of defects is correlated with average pipe wall thickness, non-uniform wall thickness of the blank, heating mode and friction conditions. The results of full-scale experiment confirm the main conclusions made in the course of the finite element simulation. The research results define the interdependence of actual size of the blank and the operating tool calibration.

Keywords: tubing, drill pipe, upsetting process, quality, FEM, experiment, tool calibration.

INTRODUCTION

Pipe ends upsetting process is a local increase of the wall thickness of a pipe at a predetermined distance from the end. Wall thickening is performed outside, inside or on both sides using dies and a punch [1, 2] (Fig. 1). Greater wall thickness increases the strength of threaded tubing connection with couplings or welded drill pipe connection with tool joints. Couplings and tool joints are used to build the pipes in the columns in the extraction of oil and gas.

Now, the conditions of oil and gas production are becoming more complex. This fact sets high demands on the quality of pipes produced. The practice of production of pipes with upset ends shows that most defects are located on the inner surface. These imperfections are surface breakings that reduce the effectiveness of pipe wall thickness [3]. They are detected close to the ends of pipes (Fig. 2). Mueller and Arem [4] show that the cause of such defects is a lower temperature at the end of the pipe relative to the rest of the heated part of the pipe. However, the temperature increase directly at the pipe end does not improve the product quality. Therefore, the purpose of this paper is to study metal forming in pipe ends upsetting process and to identify the defects associated with the process. The study involved finite element simulation and a full-scale experiment. The influence of the diameter and wall thickness of the pipe, friction conditions, temperature of the heated pipe ends and temperature of the tool on the defects creation has been studied.

FINITE ELEMENT SIMULATION

To achieve the goals of this research finite element simulation in Deform-3D was performed. The simulation was carried out for the tubing with nominal dimensions 73.02x5.51 mm in accordance with API specification 5CT [5] and for drill pipe 73x9.2 mm in accordance with Russian State Standard R 50278-92 [6]. The actual dimensions 73.23x4.82 mm and 73.81x6.2 mm of the tubing were also used taking into account the tolerances on the diameter and the wall thickness of the pipe. To study the effect of variation in blank's wall thickness on metal forming the pipe with diameter of 73.02 mm with wall thicknesses from 4.82 mm to 6.2 mm was used.

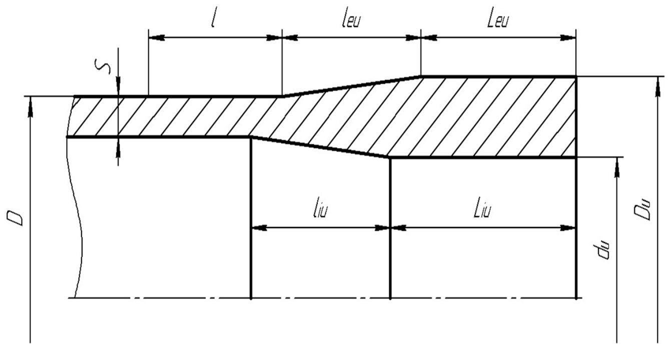

Fig. 1. Upset end of a pipe.

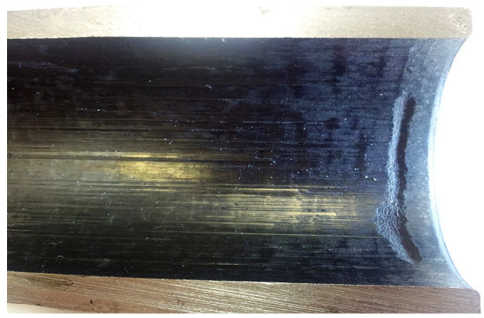

Fig. 2. The defect on the inner surface of the pipe upset end.

The steel grade AISI-1045 was selected in Deform-3D's material library. These blanks were used for computer simulation with the following upsetting process variables: Siebel friction factor is ψ = 0.3, the length and the temperature of heated pipe ends are L_h = 240 mm and T = 1200°C respectively, the dies and the punch temperature are T_d = 200°C and T_p = 130°C respectively. The tool calibration and above-named variables of the process are used taking into account the practice of production of pipes with upset ends at JSC Pervouralsk new pipe plant. In addition, the problems with Siebel friction factor ψ = 0.7, the temperature of heated pipe ends T = 1100°C, the temperature of dies T_d = 150°C and T_d = 250°C and the temperature of punch Tp = 100°C and Tp = 180°C respectively had been solved. Moreover, the temperature in narrow region near the face plane of the pipe was taken equal to $T_{f.p.}$ = 1100°C and $T_{f.p.}$ = 1290°C. All additional problems were solved for the tubing 73.02x5.51 mm upsetting. In total, 11 problems had been at the stage of computer simulation. The plan of computing experiment is shown in Table 1.

According to the simulation results, there are several stages of the upsetting process, which are characterized by different velocity fields [7]:

1. the expansion of the blank by the punch;
2. the pipe profile buckling;
3. the beginning of an intense deformation in a closed area;
4. the final shaping of the upset end.

The first stage is the expansion of the pipe by the punch begins since the punch first contacts the blank and continues until the punch contacts the face plane of the pipe. It is important to note that this stage occurs only when the diameter of the working surface of the punch is larger than inner diameter of the blank. Characteristic of stage is that the velocity values are close to zero. In this regard, there is no attention paid to this stage in literature. However, it is characterized by intensive heat removal from the heated end of the pipe through the contact surface into a cold tool (Fig. 3).

The value of cooling defines the change of metal thermomechanical behavior of blank in region close to the pipe end. The maximum temperature change near the contact surface of the blank is as follows:

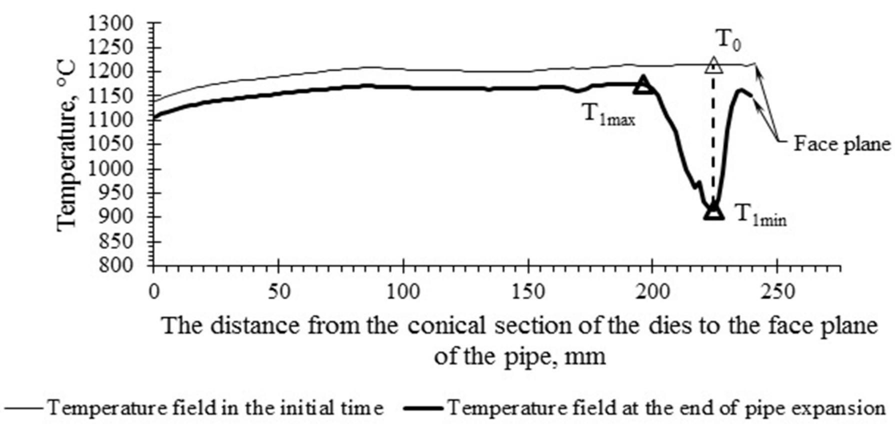

Fig. 3. Change of the temperature field of the blank during the first stage of the process.

Table 1. The plan of computing experiment.

The number of problem	Size of the blank $D \times S$ or $D \times (S_{min}–S_{max})$, mm	Siebel friction factor ψ	Initial temperature of the blank T, °C	Face plane temperature $T_{f.p.}$, °C	The temperature of dies T_d / and punch T_p, °C
1	**73,02x5,51**	**0,3**	**1200**	**1200**	**200/130**
2	**72,23x4,82**	0,3	1200	1200	200/130
3	**73,81x6,2**	0,3	1200	1200	200/130
4	**73,02x(4,82-6,2)**	0,3	1200	1200	200/130
5	73,02x5,51	**0,7**	1200	1200	200/130
6	73,02x5,51	0,3	**1100**	1200	200/130
7	73,02x5,51	0,3	1200	**1100**	200/130
8	73,02x5,51	0,3	1200	**1290**	200/130
9	73,02x5,51	0,3	1200	1200	**150/100**
10	73,02x5,51	0,3	1200	1200	**250/180**
11	**73x9,2**	**0,3**	**1250**	**1250**	**200/130**

$$K_{temp} = \frac{T_{1max} - T_{1min}}{T_{1max}} \quad (1)$$

where T_{1max}, T_{1min} and T_0 are temperature values according to the Fig. 3.

In the process of the pipe profile buckling there is a gradual increase in the outer and inner diameter of the end of the blank, whereby the contact of a pipe with a punch disappears. Then the filling of the die space starts. The die space is formed with the working surfaces of the die and the punch. The filling of the dies occurs in the direction from the periphery to the axis of the blank [8 - 10]. Due to the non-uniform deformation resistance of the metal in the axial direction specified by cooling in the initial stage of upsetting, the field of radial velocity is characterized by two local maxima (Fig. 4).

A closed air cavity appears between the surfaces of the punch and the inner surface of the pipe. It appears in the case when the metal particles that are on the boundary of domains 1 - 2 have a larger radial velocity than the particles on the boundary 2 - 3 (Fig. 4). This cavity does not disappear completely to the end of the upsetting process (Fig. 5). To quantify the tendency to the creation of defects on the inner surface of the upset pipe the following parameter is introduced:

$$K_{def} = \frac{r_2 - r_1}{L_2} \quad (2)$$

where – sizes in the radial direction according to the Fig. 4.

Fig. 6 shows the dependence of a parameter Kdef on the parameter Ktemp that characterizes non-uniform deformation resistance along the axis of the blank at the end of the stage of expansion of the pipe. It is seen from the diagram, that the inner defect is formed when the temperature of the metal in the face plane of the pipe is T = 1100°C. It is 100°C below the temperature of the rest heated part of the pipe.

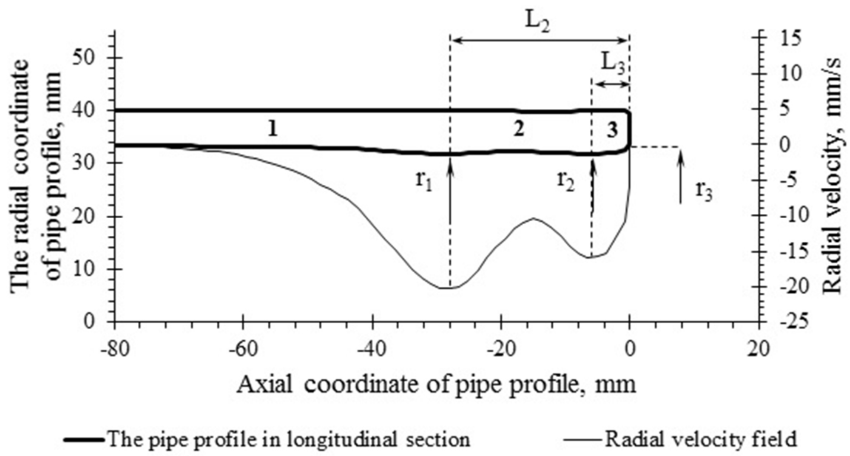

Fig. 4. Field of the radial velocity.

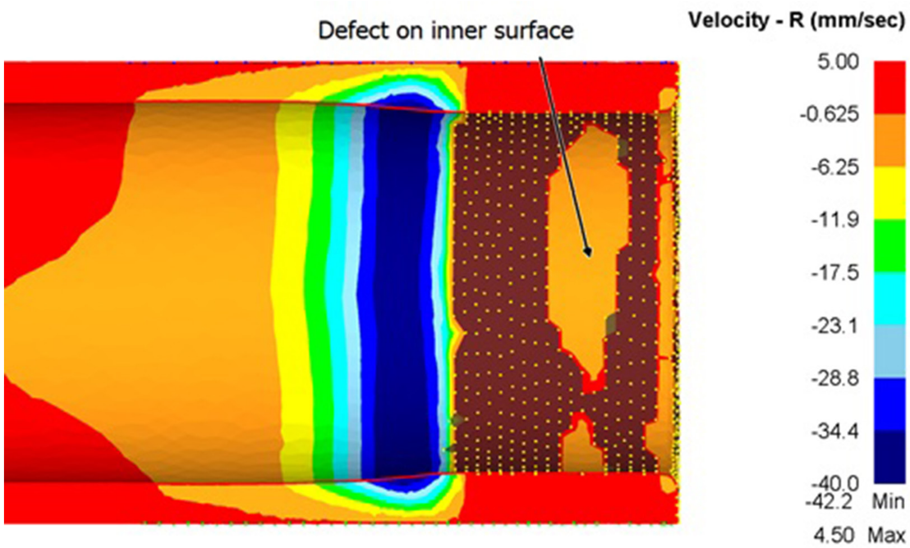

Fig. 5. Defect on inner surface creation.

The decrease of tool temperature leads to a slightly increased probability of defects formation. The increase of friction factor leads to an increased non-uniformity of deformation in the pipe end [10], which in turn increases the tendency to the creation of defects. This can be seen from Fig. 6 where the value Kdef is very different from the trend line.

The increase of the tool temperature, as well as the increase of temperature in the face plane of the pipe, provides more uniform temperature on the end of the blank. It should be noted that the values of parameter Ktemp are equal when two pipe ends are heated, one to the temperature 1200°C and the other one to 1100°C. This leads to the fact that the tendency to the creation of defects is equal in both cases.

The additional parameter is added in the paper:

$$K_{\text{tool}} = \frac{2S}{D_{\text{d}} - d_{\text{p}}} \quad (3)$$

where:

S - wall thickness of the pipe, mm;

D_d - diameter of the cylindrical part of the dies, mm;

d_p - diameter of the conical part of the punch, mm.

Fig. 7 shows the dependence of a parameter Kdef on the parameter Ktool that characterizes wall thickness of the blank relative to the clearance between the dies and the punch. It is clear that with the increasing amount of clearance between the dies and the punch, the tendency to the appearance of defects is evident. The results of simulation show that inner defects appear close to the upset end of the pipe 73.81x6.2 mm. Statistical analysis of the experimental data suggests that there is a linear

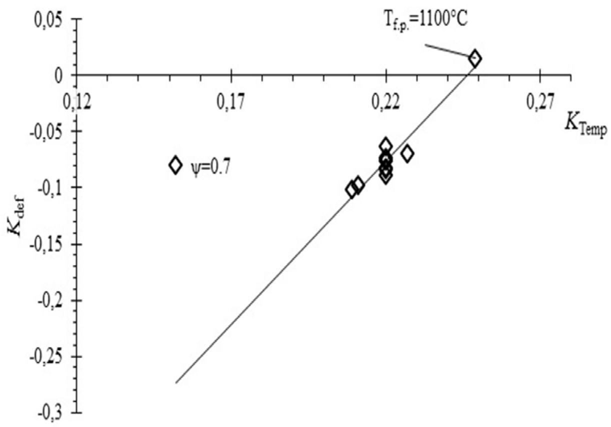

Fig. 6. The dependence of the K_{def} from K_{temp}.

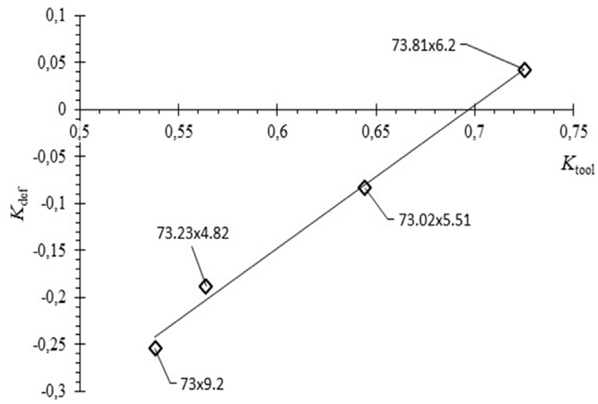

Fig. 7. The dependence of the K_{def} from K_{tool}.

relation between the parameters Kdef and Ktool regardless of the pipe dimensions and the tool sizes. Thus, correlation has been found between the tool calibration parameters with the maximum wall thickness at which the defects creation is observed:

$$S^{\max} = 0.3486 \cdot \left(D_{\mathrm{d}} - d_{\mathrm{p}}\right) \quad (4)$$

The increase of the varying wall thickness of the blank significantly increases the tendency to creation of defects on the inner surface. In this case the defect is formed not the entire perimeter of blank, and in that part where the wall thickness is minimum (Fig. 8).

FULL-SCALE EXPERIMENT

In order to confirm the results received at the stage of computer simulation a full-scale experiment was carried out at JSC Pervouralsk new pipe plant on hydraulic press made by SMS Meer. Blanks with nominal dimensions 73.02x5.51 mm were chosen for this experiment. According to the existing tool calibration at JSC Pervouralsk new pipe plant and formula [4] the maximum wall thickness is 5.96 mm. Blanks with the average wall thickness 5.28 mm, 5.36 mm, 5.49 mm, 5.79 mm, 5.87 mm and 6.09 mm were chosen for the full-scale experiment. The upsetting was made with the following process variables: the length of the heating pipe ends is Lh = 310 mm, the heating temperature is T = 1290°C, the pressure in the main hydro cylinder is 10 MPa, time delay before moving the punch in the opposite direction is 1.8 seconds.

The full-scale experiment has shown that the pipe in which inner defects were found had wall thickness equal to 6.09 mm. It exceeded the maximum wall thickness equal to 5.96 mm. Inner defects were not found on the rest pipes with wall thickness of less than 5.96 mm. Thus, the full-scale experiment has confirmed the validity of formula [4] that allows to establish requirements either to blanks coming on the upsetting operation, or to the tool

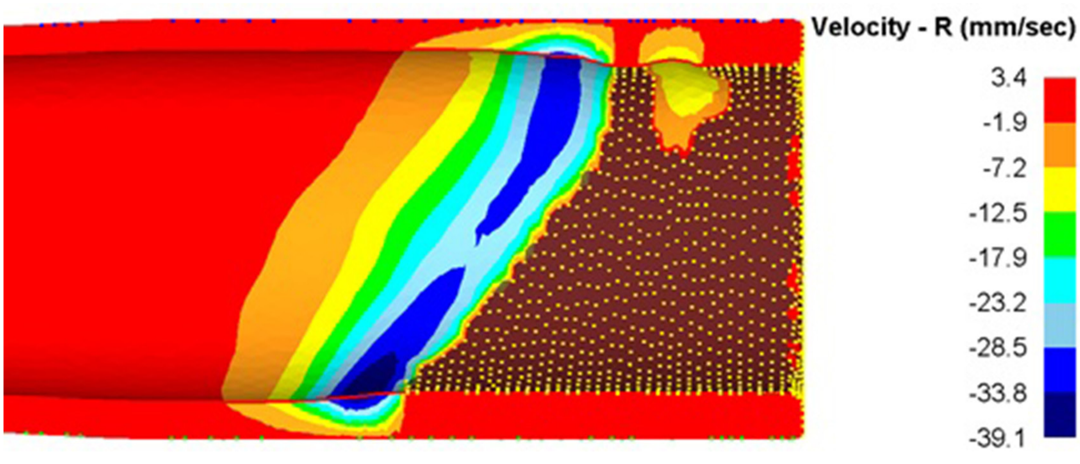

Fig. 8. Defect on the inner surface of the pipe with non-uniform wall thickness.

Fig. 9. Upset end of drill pipe 73x9.2.

calibration based on the actual dimensions of the pipes.

Fig. 7 shows that the parameter Kdef is minimal in the case of upsetting the drill pipe with dimensions 73x9.2 mm in accordance with State Standard R 50278-92 in one pass. It is caused by the fact that the step of expansion of pipe is omitted. So, inner defects near the pipe end are excluded. The experimental work was carried out at JSC Pervouralsk new pipe plant to test the possibility of upsetting drill pipes 73x9.2 mm in an industrial environment in one step. As a result, 30 tons of the pipes were successfully treated and the coefficient of the pipe wall thickening was about 1.85. Defects on the inner surface of the pipes were not detected (Fig. 9). This confirmed the results of theoretical research.

CONCLUSIONS

This paper presents theoretical and industrial research on pipe ends upsetting process in one step. Special attention is paid to the quality of inner surface of final products. The results of computer simulation show the influence of technological parameters of upsetting on defect formation on the inner surface of the pipe. Full-scale experiment confirms the correlation between maximum wall thickness and the calibration parameters of the process tool formula [4].

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