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Trans. Nonferrous Met. Soc. China 22(2012) s329−s334
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Control strategy of over-bending setting round for pipe-end of large pipes by mould press type method

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Received 28 August 2012; accepted 25 October 2012

Abstract: The setting round process is one of the most important processes to ensure the quality of large pipe products. The setting round for pipe-end is a local elasto-plasticity deformation process, so it is difficult to quantificationally analyze the springback law because of the influence of rigidity. The physical experiments were used to study the equivalence relation between the setting round process for pipe-end and the circle-to-oval process for pipe-end, and the similarity relation between the circle-to-oval process for pipe-end and the circle-to-oval process for short pipes. The results indicate that the reductions are equal both in the setting round process and the circle-to-oval process for pipe-end; the relationship between the ovality after unloading and the relative reduction is linear in the circle-to-oval process both for pipe-end and the whole pipe, and the horizontal axis intercepts of the two lines are equal. Based on the relation above, the two-step control strategy of over-bending setting round for pipe-end was built, which can control the residual ovality of pipe within 0.5%.

Key words: large pipes; pipe-end; over-bending setting round; rigidity influence; control strategy; two-step method

1 Introduction

With the development of piping engineering for conveying western gas and oil to the east and the infrastructure construction in the field of electricity generation, there arise more and more demands for the steel pipes, therefore the quality requirements for all kinds of pipes become increasingly strict [1,2]. Both of the pipe body ovality and the pipe-end ovality are the main indexes to evaluate the quality of steel pipe products. According to the U.S. Pipe Association API Spec 5L standard, the pipe body ovality of finished pipes should not exceed 1.0% of the pipe’s nominal diameter [3]. But for the pipe-end, if the ovality is out of standard, it will directly lead to the problem in the turning of welding groove, and then influence the connection process between the two pipes in practical application. Therefore, the requirement for pipe-end ovality is stricter than for pipe body.

At present, according to the features of pipe products, the ways of setting round are different [4−7]. While the common way to correct the pipe-end ovality is using a pair of little curvature circular arc moulds to press the pipe-end repeatedly, to make the pipe wall deform plastically so as to achieve the purpose of pipe-end setting round. This method has lots of advantages, such as easy operation, low cost and comparatively good effect, but it lacks theory guide, and operators mainly rely on their experience, so it reduces the productivity effect. Therefore, manufacturers urgently need the quantificational analysis results to direct the control strategy of setting round process.

According to the technological characteristics of over-bending setting round process, the deformation zone of pipe billet is concentrated in a small region near the pipe-end. The undeformed part of the pipe exerts a great influence. So, it is difficult to resolve the problem and give the right technological parameters by theoretical formulas. However, if the rigidity influence is neglected in the process, the problem can be considered to be a plane strain problem.

BAYOUMI and ATTIA [8] analyzed shaping a circular pipe into a square section. It was suggested that the setting round process can be considered a pure bending problem.

YAN et al [9,10] gave the FEM equivalent model for the bending forming of aircraft integral panel. SU et al [11] researched the springback law in the cap-shape bending process. NATARAJAN and PEDDIESON [12]

Foundation item: Project (51175452) supported by the National Natural Science Foundation of China; Project (E2012203061) supported by the Natural Science Foundation of Hebei Province, China
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DOI: 10.1016/S1003-6326(12)61727-0

gave the moment/curvature relationships of plane flexure by the linear elastic/perfectly plastic behavior material model. FU and MO [13] predicted the springback amount of air bending problems by means of neural network. ZHAO et al [14,15] gave the springback law of beam in plane bending process. The studies supplied the base for the theoretical research for the setting round process.

Through experiment, this work researches into the equivalence relation between the setting round process and the circle-to-oval process for pipe-end of long pipe, and the similarity relation in the circle-to-oval process between the pipe-end of long pipe and the whole short pipes. Furthermore, the two-step method control strategy of over-bending setting round process for pipe-end is given.

2 Summary of over-bending setting round and experimental facility

The long pipe is initially oval of an outer semi-major axis b_0 and semi-minor axis a_0 and a uniform wall thickness t. The pipe-end is compressed between two symmetrical circular arc tool surfaces through equal displacements along with the direction of semi-major axis. According to the Saint Venant principle, the pipe can be separated into three parts along with the axial direction. One is the main deformation zone in contact with the tools, and the length is L. The rest are implicated deformation zone and undeformed zone.

As shown in Fig. 1, the deformation process of the main deformation zone consists of unbending of the point B and its neighboring region to become less curved, and bending of the point A and its neighboring region to become more curved. Taking the springback into consideration, the vertically oval section pipe must be compressed into horizontally oval section, then, the

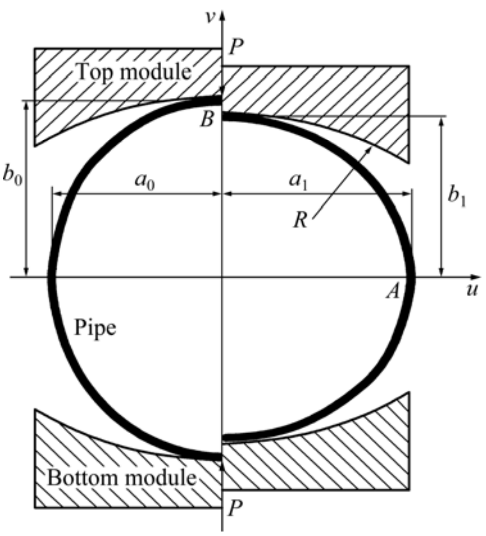

Fig. 1 Sketch of mould press type over-bending setting round

shaping into a round section can be available after the springback. To be visual, the process is named "oval-to-circle process". However, the inverse process, which is shaping a circular section pipe into an oval section by the same way as the oval-circle process, is named "circle-to-oval process".

Over-bending setting round experiment was carried out on the WDD−LCT−150 multifunctional testing machine. Its displacement control precision was 0.01 mm. According to the similarity principle, the specimen/actual pipe ratio is 1:10. The outside diameter of the specimen is d76.2 mm, the wall thickness is 4 mm, and the length of long pipe is 500 mm. The material is 20 steel. The radius of the module chamber is 120 mm, and the width is 120 mm. To reduce the stress concentration that was caused by module, one side of the modules was processed to be a chamfer angle, with the cone angle of 7° and the length of 20 mm. The picture of the modules and specimen are shown in Fig. 2.

Fig. 2 Modules and specimen

3 Equivalence relation of pipe-end over-bending setting round

To lower the difficulty, the experimental method was used to analyze the over-bending setting round process for pipe-end and the oval-circle process is compared to the circle-oval process experimentally for the confirmation of the correlativity between the two processes. Then, the probability that the deformation law of circle-oval process is used for the technology making in the oval-circle process is looked for.

Taking circular section long pipe as the experimental subjects, the experiment project was set down as follows. First step is the circle-to-oval process for pipe-end of long pipe. The initial circular section pipe-end is pressed into oval shape with certain reduction h and certain main deformation zone length L, and the ovality after unloading is noted. Second step is the oval-to-circle process for pipe-end of long pipe. The oval shape pipe after the first step rotates 90° along with its axial direction, and is pressed in the same way and the same technological parameters as the first step, and then the residual ovality after unloading is also recorded.

The definition of ovality is

$$\delta = \frac{a-b}{R} \times 100\% \tag{1}$$

where a is the outside surface semiaxis of the pipe wall in u direction, b is the outside surface semiaxis of the pipe wall in v direction; and R is the outside radius of the initial circular section pipe. For the oval pipe needed to be set round and the pipes with initial diameter are unknown,

$$R = \frac{a+b}{2} \tag{2}$$

The experiment results under different reductions and different main deformation zone lengths are shown in Table 1, where the definition of the relative reduction is

$$H = \frac{h}{R} \times 100\% \tag{3}$$

Table 1 Experimental results of equivalence relation

No.	H/%	L/mm	Ovality after first step/%	Residual ovality/%
1	5.25	60	0.81	0.26
2	7.87	60	2.76	0.19
3	10.50	60	5.12	0.21
4	7.87	80	2.94	0.31

Table 1 shows that, the maximum residual ovality of pipe-end is 0.31 mm, and the minimum is 0.19 mm, which are much less than the 1% requirement of the pipe standard, and the values of residual ovality are all positive. This indicates that the work hardening of the pipe after the first deformation is the main reason for the residual ovality, when the same pipe billet is used to undergo the two experimental processes.

The experimental results suggest that under the precision range of the engineering requirement, the oval-to-circle process for pipe-end is equivalent to the circle-to-oval process for pipe-end of circular section pipes. The so-called equivalent means that the reductions of two processes are equal under the conditions that the material of the pipe, the thickness of the wall, the section perimeter are the same, and the ways of mould-press type are also the same. To be brief, the oval-to-circle is equivalent to the circle-to-oval. Thus, it can be proved that the reduction, with which pipe-end of circular section long pipe is pressed into oval shape, is used to set round the pipe-end with enough precision, under the conditions that the ovality of pipe needed to be set round is equal to the pipe ovality that circular section pipe forms into.

4 Similarity relation about rigidity influence

Taking the circular section long pipe and short pipe of the same material and specifications as the study objects, the pipe-end of long pipe as well as the whole short pipe are compressed radially with certain L and H. The force—stroke curve and the ovality after unloading are recorded. And then, their similarity is researched into, so as to build the connection of technological parameters in both processes.

When L=60 mm, the stroke—load curves in the circle-to-oval process both for pipe-end of long pipe and for the whole short pipe are shown in Fig. 3. When the stroke is small, the pipes are in fully elastic deformation stage, and the load values do not differ much. However, when the pipes yield, the ascendant trend of load for pipe-end is steep, while the ascendant trend for the short pipe is even. Comparing the load values, when the stroke is 4 mm, the ratio is 2.12. There is a big deviation.

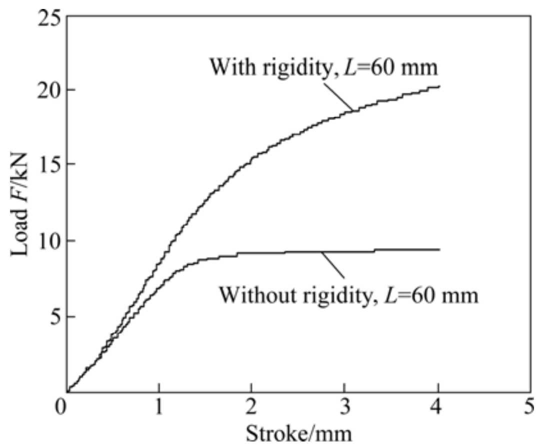

Fig. 3 Force—stroke curve with and without rigidity

The correlation curves of ovality after unloading and relative reduction in the circle-to-oval process are shown in Fig. 4, when the main deformation zone length is 40 mm and 60 mm respectively, and the length of short pipe is 60 mm.

From the results shown in Fig. 4, it is known that, when the relative reduction is equal, the ovality of pipe-end of long pipe after unloading is smaller than the ovality of short pipe. This means that the springback is larger when the pipe is affected by the rigidity. However, under the two deformation modes, ascendant trend of the curves is identical. When the relative reduction is small, both of the pipes are in fully elastic deformation stage, and the ovality does not change after unloading. While with the increase of relative reduction, the relationships between ovality after unloading and relative reduction are all linear. The relative reduction and ovality data in

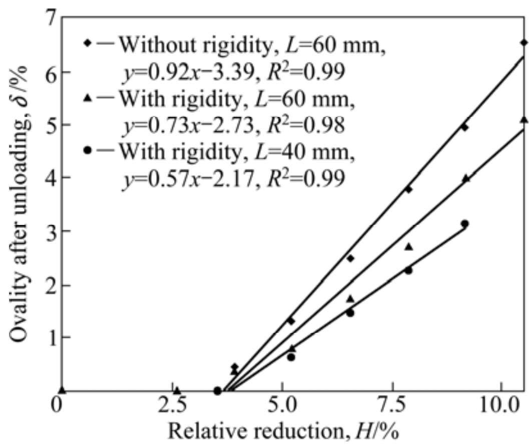

Fig. 4 Curves of ovality after unloading and relative reduction

the plastic area in both processes are linearly fitted, and the linear related coefficients are all beyond 0.98, very close to 1.

According to the linearly fitting results of the experimental data, the horizontal axis intercepts are 3.68, 3.73 and 3.80. The errors of the three values are small, which are almost equal under the error requirement range of the engineering.

When L is different, comparing the results of the circle-to-oval process for pipe-end, it is known that the slope of the line when L=40 mm is smaller than that when L=60 mm, which means that the slope gradually increases along with the increase of L, until the slope is equal to the slope in the circle-to-oval process for short pipe. When L is long enough, the rigidity influence can be ignored.

According to the experimental results above, the following conclusions can be given.

1) In the circle-to-oval process, for both short pipe and the pipe-end of long pipe, the relationship between the ovality after unloading and the relative reduction is linear when the pipe deforms plastically, under the conditions that the material and pipe specifications of the two types of pipe are the same.

2) Under the error requirement range of engineering, the horizontal axis intercept in the liner relationship between ovality after unloading and the relative reduction in the circle-to-oval process both for short pipe and pipe-end of long pipe is equal.

3) In the circle-to-oval process for pipe-end, the slope increases along with the increases of L. It means that the longer the L is, the nearer the line to that in the circle-to-oval process for short pipe is.

5 Two-step control strategy of over-bending setting round for pipe-end

The sketch of two-step control strategy is shown in Fig. 5. According to the equivalence relation of over-bending setting round above, it can be deduced that the abscissa of the start point and the slope of the line in both the circle-to-oval process for pipe-end and the oval-to-circle process for pipe-end are equal, which means the slope and the abscissa of the start point of lines 2, 3 and 4 in Fig. 5 are equal. Based on the similarity relation above, the abscissa of the start point of the lines in the circle-to-oval process both for pipe-end and the short pipe are equal, and it is equal to the horizontal axis intercept H_y of the line in the circle-to-oval process for short pipe. The linear equation of circle-to-oval process for short pipe can be given by quantificational mechanical analysis or simulation experiment.

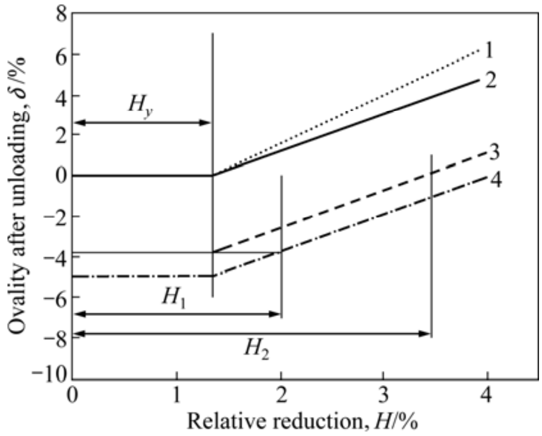

Fig. 5 Sketch of two-step control strategy: 1—Circel-to-oval process for whole pipe; 2—Circle-to-oval process for pipe-end; 3—Setting round process when initial ovality is δ_0; 4—Setting round process when initial ovality is δ_1

Thus, the two-step control strategy is built. The initial long pipe with the ovality δ_0 is pressed by two steps to correct the ovality of pipe-end.

In the first step, with the definite relative reduction H_1, the pipe-end is pressed plastically. The ovality after unloading δ_1 is noted.

In the second step, using the line 1 which is known and the relation in Fig. 5, the relative reduction H_2 can be calculated, and then the pipe-end is pressed in the second time to finish the setting round process.

The computational method of H_2 is as follows.

The equation of line 1 is

$$\delta=F'H+G' \tag{4}$$

where F' is the slope and G' is the intercept in the linear relationship. From this relationship H_y is given by

$$H_y=-\frac{G'}{F'} \tag{5}$$

The equation of line 2 is

$$\delta=F_0H+G_0 \tag{6}$$

Similarly, F_0 is the slope and G_0 is the intercept in the linear relationship.

When the initial ovality is δ_0, the linear relationship between the ovality after unloading and the relative reduction in oval-to-circle process for pipe-end, which is line 3, is

$$\delta=F_0H+G_1 \tag{7}$$

where G_1 is the intercept in the linear relationship. The start point of this line is (H_y, δ_0). According to the results of the first step, the point (H_1, δ_1) is also on the line, where H_1 is the relative reduction in first step. Then, F_0 is given as

$$F_0=\frac{\delta_1-\delta_0}{H_1-H_y} \tag{8}$$

The residual ovality is δ_1 after the first step. When the ovality is δ_0, the linear relationship between the ovality after unloading and the relative reduction in oval-to-circle process, which is line 4, is

$$\delta=F_0H+G_2 \tag{9}$$

where G_2 is the intercept in linear relationship. The start point of this line is (H_y, δ_1), and the slope is F_0. Substituting Eq. (5) and Eq. (8) into Eq. (9), G_2 can be given. When δ=0, the relative reduction, which is the second step relative reduction, is given by

$$H_2=\frac{F'H_1\delta_1+2G'\delta_1-G'\delta_0}{F'(\delta_0-\delta_1)} \tag{10}$$

6 Verification experiment of control strategy

According to the two-step control strategy of over-bending setting round for pipe-end, three pipes with different initial ovality are chosen to carry out the verification experiments, and the results are shown in Table 2. The specification of long pipe is the same with the pipe in the experiment of equivalence relation. The main deformation zone is 60 mm. The initial ovality pipes are prepared by pressing the circular section pipes in the radial direction. The F' and B' values in the circle-to-oval process for short pipe, which are used in the control strategy, are equal to the experimental results in Fig. 4. The first step relative reduction is the identical 5.25 mm.

From the experimental results, the maximum residual ovality is 0.34, and the minimum is 0.08, the final results are still fluctuating in a small range, indicating that the approximative similarity relation used in the control strategy and the fluctuation of material properties impose certain influence the setting round process. However, the final results do totally meet the requirement of pipe standard. Thus, it is proved that the control strategy established in this paper can be used in the actual production.

Table 2 Experimental results of control strategy

No.	δ_0/%	H_1/%	δ_1/%	H_2/%	Residual ovality/%
1	−2.62	5.25	−1.10	4.80	0.08
2	−2.99	5.25	−1.44	5.14	0.29
3	−3.28	5.25	−1.78	5.54	0.34

7 Conclusions

1) The reductions that the setting round process and the circle-to-oval process need are equal, under the conditions that the material, the thickness of the pipe wall, the section perimeter, and the way of mould-press type are the same, and the ovality of pipe needed to be set round is equal to the pipe ovality that the circular section pipe forms into.

2) The similarity relation exists in the circle-to-oval process both for pipe-end of long pipe and short pipe. The so-called similarity means that the relationship between the ovality after unloading and the relative reduction is linear in the plastic deformation stage in both of the processes and the horizontal axis intercept of the lines is equal.

3) The verification experiment indicates that, the two-step control strategy of over-bending setting round for pipe-end, can control the residual ovality within 0.5%.

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大型管件模压式管端过弯矫圆的控制策略

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摘 要：管端矫圆是保证大型管件产品质量的重要工序之一。管端矫圆是一个局部弹塑性变形过程，由于刚端的影响而导致难以对其弹复过程进行定量解析。采用物理模拟实验方法，研究管端扁矫圆与管端圆压扁之间的等价关系，以及管端圆压扁与整管圆压扁之间的相似关系。结果表明：管端扁矫圆和管端圆压扁的压下量相等；管端圆压扁和整管圆压扁卸载后椭圆度与相对压下量均为线性关系，且两条之间的横轴截距相等。基于上述关系，建立了管端矫圆两步法控制策略。验证实验表明，该控制策略可以将残余椭圆度控制在 0.5%以内。

关键词：大型管件；管端；过弯矫圆；刚端影响；控制策略；两步法

(Edited by YUAN Sai-qian)