Journal of Mechanical Engineering Research and Developments
ISSN: 1024-1752
CODEN: JERDFO
Vol. 43, No. 3, pp. 385-393
Published Year 2020

Microstructure Of The Nickel-Base Aging Martensite Alloy After Spinning Process Of Thin Tube At Different Strain Reduction

Le Trung Kien[1], Nguyen Thai Hoc[2], Pham Van Cuong[2], Le Thai Hung[3*]

[1]School of Mechanical Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam

[2]Institute of Technology - General Department of Military Industries and Manufacture

[3]School of Materials Science and Engineering - Hanoi University of Science and Technology

*Corresponding Author email:: hung.lethai@hust.edu.vn

ABSTRACT: Tube spinning is an advanced forming process to produce thin-walled tubular workpieces with high precision and improved mechanical properties, widely used in aviation, chemistry, power industries... In this study, the effects of spinning deformation and subsequent heat treatments on the mechanical properties and microstructure of the nickel-base aging martensite alloy were evaluated comparatively with the perform. Plastic deformation during spinning elongated the grains severely in the direction of metal flow. The solution treatment resulted in a drastically refined grain and recrystallised microstructure, removing the effect of plastic deformation. The results show that with the increase of spinning pass, the fiber microstructure comes into being gradually in axial direction and the circumferential microstructure also stretches obviously along circumferential direction. At the same time, the tensile strength increases in axial direction.

KEYWORDS: Spinning, thin tube, microstructure, mechanical properties, martensite alloy

INTRODUCTION

Tube spinning is known in industry by variety of names such as; shear forming, tube spinning, flow turning, flow forming, rotary extrusion, roll extrusion, hydrospinning, and rotoforming [1,2]. Typical products of tube spinning include pressure vessels, automotive parts, space shuttles components, rockets and missiles parts and a great variety of very high strength with light weight tubular components[1]. Most of tube spinning applications use rollers located outside the tube having the mandrel defining its inner diameter, (external spinning) [1,2]. However, in some applications the rollers may be located inside the tube having the mandrel defining its outer diameter (internal spinning) [1]. In tube spinning, from the incompressibility rule, this reduction in thickness of the pre-form leads to an increase in its length. The deformation region is only in the contact zone between pre-form and rollers. The pre-form is placed on rotating and sliding over the mandrel, while the internal diameter remains constant [3].

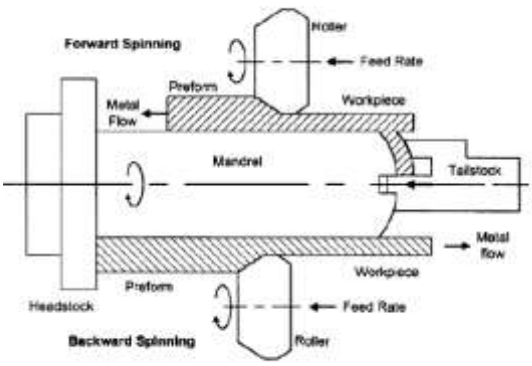

Figure 1. Forward Spinning process principle

The tube spinning process is classified into two methods: forward and backward. These methods are defined according to their material flow during the process [4]. In this study a forward spinning was employed, in which the material flow is in the same direction as the roller feed direction. The principle of forward spinning is shown in figure 1. The importance of flow forming in manufacturing tubular parts, some theoretical analyses and experimental investigations have been performed and reported in the literature. The influences of flow forming parameters such as feed rate, contact surface, and microstructure on the quality of D6ac steel were studied by Jahazi and Ebrahimi [5]. They implied that defects depended to attack angle of the roller and the thickness reduction. Rajan and Narasimhan investigated the defects developed during flow forming of high strength SAE 4130 steel tubes experimentally and finally categorized the flow forming defects as microcracks, macrocracks, diametral growth, ovality, fish scaling, and premature bursting [6]. The cold power spinning process experimentally are studied, and they improved the microstructure of Ti-15-3 alloy during the cold spinning and controlled the diametral growth by variation of the thickness reduction, the feed rate and wall thickness of the preform [7]. Using finite element methods, Wong et al carried out a numerical study to investigate the effects of feed rate and roller geometry on material flow using the finite element model [8,9].

The finite element method (FEM) are used to control the shape, size and precision of the finished parts, reducing defect rates. According to Jiang Shu Yong, this method is used to study the multi-pass spinning of thin-walled tube sections with vertical ridges [10]. The FEM method indicates the distribution of strain reduction in different strained areas. FEM simulation results indicate that the increase of three components of spinning force along with spinning causes metal during multi-pass spinning process. Meanwhile, Jae-Woo Park utilizes upper-bound method to analyze tubular spinning process [11]. The simulation has shown the necessary force coefficient is dependent on drag coefficient and optimized rolling shaft deflection angle. Peter Sugar's experimental method uses 3D optical scanning to study the impacts of technological parameters on wall thickness during traditional metal spinning of Cr-Mn austenitic stainless steels [12]. Sandeep Kamboj analyzes the impacts of different tools on the spinning process. Mahesh Shinde conducts a study on metal formation process by examining metal spinning enhancement of metal spinning's mechanical attributes and parameter [13,14]. Peter Šugár et al analysed the effect of process parameters on part wall thickness variation in conventional metal spinning of Cr-Mn austenitic stainless steels [15]. They indicated that feed ratio and roller path profile are statistically significant factors governing wall thickness variation. There was no obvious effect from the variation of mandrel speed on the thickness distribution. Sangkharat Thanapat et al studied the effect of some process parameters [16].

They compared the experimental and numerical simulation of metal sheet spinning has been applied to investigate the effect of spinning process parameters in order to achieved lower force and large deformation without the wall breakage or wrinkling failure. Frnčík et al analysed the chosen conventional metal spinning parameters (tool path profile, mandrel speed and the tool feed rate) on the wall thickness variation of cylindrical shaped spun-parts are studied [17]. They indicated the effect of the mandrel speed was not clearly observed. Studies on metal spinning still focuses on metal spinning technology research using experimental methods and FEM, none of which examines thoroughly the microstructure of materials during the spinning process. The purpose of studying microstructure is to determine the mechanism of the spinning process, diagnosing technological errors thus devising mechanical properties enhancement solutions to prevent errors. Therefore, the requirement for researching thin-walled tubular spinning technology and material microstructure at different strain reduction level are necessary. In this paper, the paper is structured as follows: Materials and experimental conditions are introduced in the second section. The third section presents the results and discussion. In this section, the microstructure and tensile strength of tube after spinning will be discussed. Conclusions are reported in the final section.

EXPERIMENTAL PROCEDURE

Materials

The research material is made from 03H18K9M5TЮ alloy steel of Russian equivalent to the Ni18-P300 stainless steel of United Stated standard. The chemical composition of the steel is given in table 1.

Table 1. Chemical composition of alloy steel 03H18K9M5TЮ.

Elements	**C**	**Ni**	**Co**
Wt. %	≤ 0.03	17.50 ÷ 19.00	8.00 ÷ 9.00
Elements	**Mo**	**Ti**	**Al**

Wt. %	4.80 ÷ 5.20	0.69 ÷ 0.90	0.05 ÷ 0.15

The spinning workpiece has the same measurements and hardness of unmodified workpiece before spinning (≤ 34 HRC is required). The data is displayed in figure 2 and table 2.

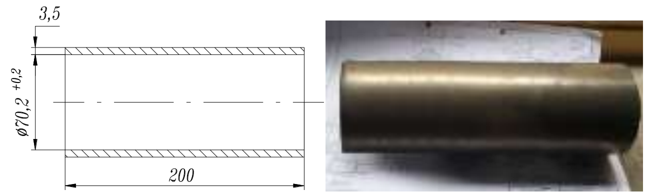

Figure 2. Spinning workpiece dimensions

Table 2. Hardness of workpiece sample used for the study

Notation	1	2	3	4	5	6	7	8	9	10
Hardness HRC	30,8	31	30,5	31	31,6	30,5	31,55	30,7	32	31,7

Upon examining the microstructure of the input workpiece, the sample contains multi-faceted, fine and evenly distributed particles. The fine particle structure ensures that the workpiece does not crack or break during the spinning process (figure 3). The grain size is almost similar in whole sample and of about 10μm.

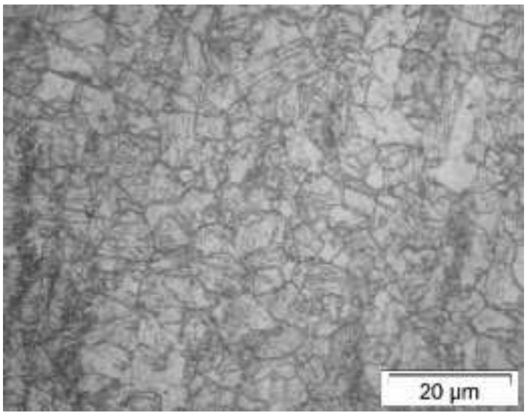

Figure 3. Workpiece microstructure before tubular formation, x1000

Experimental conditions

The material used to manufacture the thin-walled tube workpiece in this paper has high durability and hard strain reduction during the spinning process. Initial workpiece thickness is ~ 3.5 mm. Due to hard strain reduction, the process is separated into 3 steps. The workpiece is then normalized to reduce rigidity and increase elasticity. The three steps are correlated to one another, with the output of step 1st being the input of steps 2nd and 3rd. Spinning device: *RL50E – CNC*, manufactured in Spain. The chemical makeup of the sample is determined on the *SPECTROLAB* emission spectrum analyzer. Tensile strength is tested on the *HW2-1000KN* testing machine. Workpiece hardness is determined on the *FM-100* from Germany. Workpiece microstructure is measured on the *Axiovert 25* optical microscope with 50-2500x magnification. Heat treatment is performed using workpiece aging device *ПН-31*, which is a ϕ1200 x 1500mm gas furnace with initial vacuum suction. This device is used for workpiece annealing after spinning.

Absolute thickness reduction (ε) is defined with the following formula:

$$\varepsilon = \frac{d_0 - d_i}{d_0},$$

Whereas d_0 is wall thickness before spinning, d_i is wall thickness at i spin(s).

Figure 4 shows the experimental procedure for investigating the relationship between grain size and wall thickness reduction.

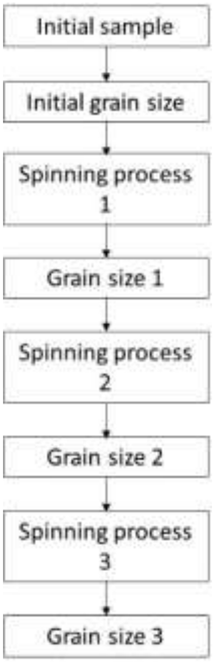

Figure 4. Experimental procedure during spinning

Step 1^{st} spinning and annealing process

Step 1^{st} spinning reduced the wall thickness from 3.5mm to 2.1mm. This means the absolute thickness reduction compared to the initial workpiece is $\varepsilon_1 = (d_1 - d_2)/d_2 = (3.5 – 2.1)/3.5 = 0.4$. The calculation must be performed accurately in order to achieve required measurements. The size of the spun cylindrical workpiece is determined by the principle of constant volume criterion during deformation (figure 5).

Figure 5. Workpiece after step 1^{st} spinning

Step 2^{nd} spinning and annealing process

At step 2^{nd} spinning. The desired wall thickness is 1.1mm, or the absolute thickness reduction (wall thickness reduction compared to original workpiece) should be $\varepsilon_2 = (d_1 - d_2)/d_1 = (3.5 – 1.1)/3.5 = 0.68$ (figure 6).

Figure 6. Workpiece after step 2^{nd} spinning

Step 3rd spinning and annealing process

At step 3 spinning. The desired wall thickness is 0.48mm, or the absolute thickness reduction (wall thickness reduction compared to original workpiece) should be $\varepsilon_3 = (d_1 - d_3)/d1 = (3.5 - 0.48)/3.5 = 0.86$ (figure 7).

Figure 7. Workpieces after step 3rd spinning

Original workpiece and tubes after each spinning went through the same precipitation hardening. The heat treatment process can be described as followed: Workpieces are clamped and loaded into the furnace. Vacuum pump is then initiated to help residual air pressure achieve 10^{-1} bar. Inert gas is then released into the furnace during the whole process. Next, aging experiment is conducted at $(490 \pm 5)^0$C with a 480-minute aging period and then the sample is air-cooled. A diagram for workpiece aging heat treatment process is presented in figure 8.

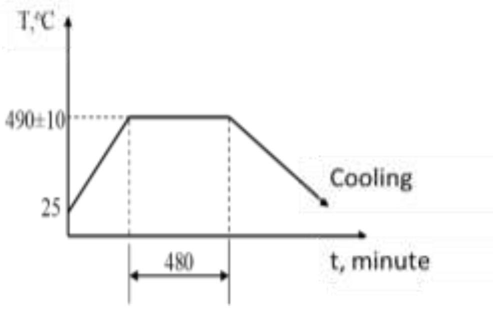

Figure 8. Heat treatment of workpiece

RESULTS AND DISCUSSIONS

Microstructure at spinning steps

Workpiece microstructure after spinning is shown from figures 9-11. Observation indicates materials have been deformed by a great margin. Structural state is composed of multi-edged uneven particles. This can be explained by looking at the sample’s composition: The percentage of alloys present constitutes a large amount of the total chemical elements: 18% nickel and 9% cobalt. These elements are easily soluble in the iron lattice network creating a hardened solution. Molybdenum occurs for 5% and can be found in particle boundaries. The element combines with others to form intermediate alloys, combining with Carbon to form MoC, which is not easily prone to strain.

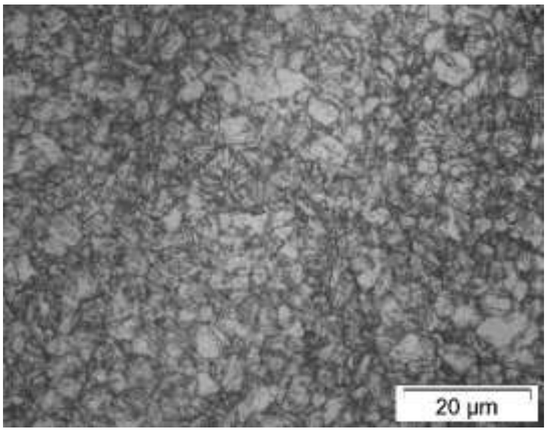

Figure 9. Microstructure of sample after step 1st spinning (2.1mm thickness), x 1000

With each spin, the size of crystalline particles will reduce. The grain size after step 3rd is almost similar in whole sample and of about 2μm. The absolute wall thickness reduction from (0.40÷0.86) can be observed on microstructure images (figure 9-11). Size of material particles decrease with each spinning, which consequently raises metal durability. This relationship will be discussed in the next section.

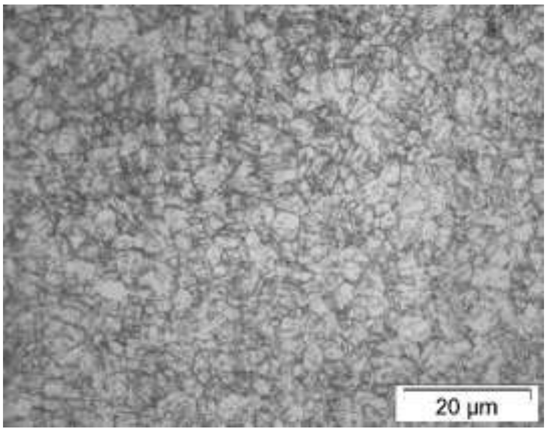

Figure 10. Microstructure of sample after step 2nd spinning (1.1mm thickness), x 1000

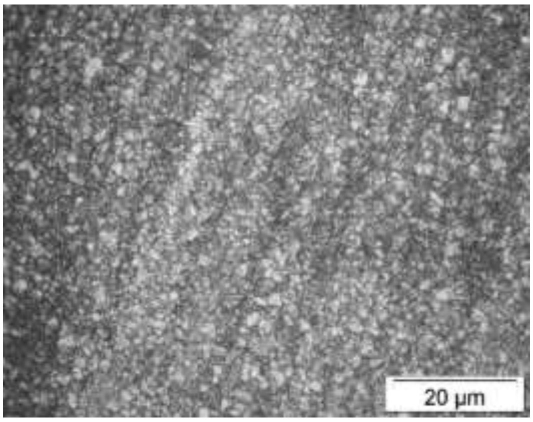

Figure 11. Microstructure of sample after step 3rd spinning (0.48 mm thickness), x 1000

Tensile strength after spinning

Post-aging workpieces are modeled to test tensile strength, with each tube corresponding to one step of spinning. 3 samples of each step were taken for testing, with the result being the median of test figures. Table 3 elaborates the tensile strength test at different spinning stages.

Table 3. Tensile strength test results of workpieces at different wall thickness reduction levels through each spinning

No	Sample status	Thickness reduction,%	Tensile strength, MPa
1	Initial	0.00	1973.82
2	Spinning 1st	0.40	2014.34
3	Spinning 2nd	0.68	2156.28
4	Spinning 3rd	0.86	2242.13

Sample image of tensile strength is shown in figure 12.

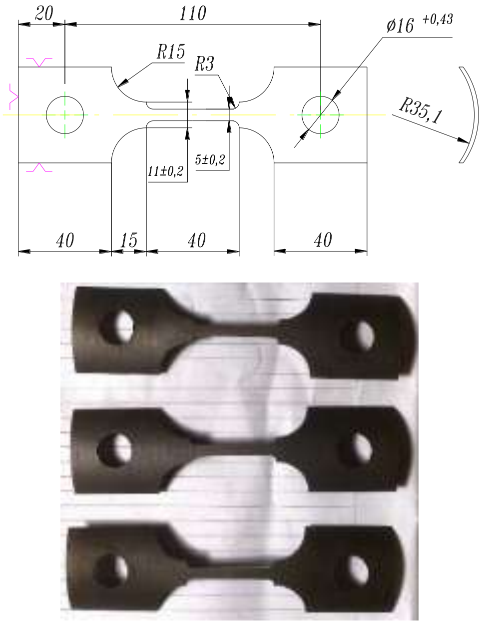

Figure 12. Tensile testing sample from spinning workpieces

The test results are shown in table 3. From table 3, it can express the relation between the tensile strength of the material and the absolute reduction in wall thickness after each spin can be displayed in figure 13. By reducing wall thickness from 3.5mm to 0.48mm through step 3rd spinning, it can be seen that the smaller the grain size, the greater the tensile strength. When absolute wall thickness reduction increases from 0 to 0.86; tensile strength increases from 1973.82 to 2242.13 MPa.

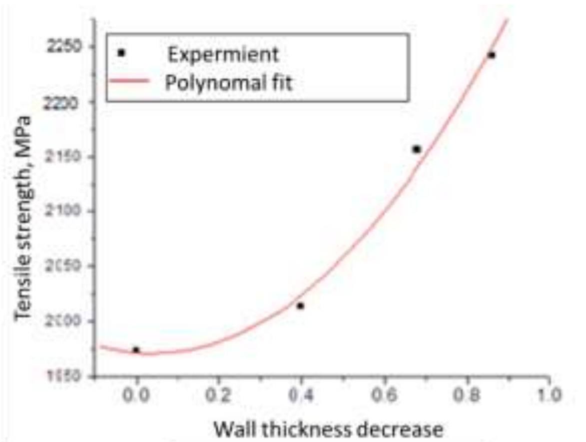

Figure 13. Relationship between absolute wall thickness reduction and tensile strength

CONCLUSIONS

Based on the results obtained from this investigation and the statistical analysis, the following conclusions can be drawn:

- With the increase of spinning pass, the fiber microstructure comes into being gradually in axial direction and the circumferential microstructure also stretches along circumferential direction. The microstructures in the preform and spun tubes are profoundly different upon complete heat treatment. The former has large grains with workpiece, and the latter possesses superfine grains with after spinning.

- Tubes after being formed by spinning possess particles affected by shear strain along the direction of metal spinning. After the aging process at 490^0C, tensile strength increased due to a series of intermediate phase. Tensile strength increased from 1973.82 (preform) to 2242.13 (after spinning 3^{rd} steps).

REFERENCES

[1] M.J. Davidson, K. Balasubramanian, K., and G.R.N. Tagore, “Experimental investigation on flow-forming of AA6061 alloy-A Taguchi approach”, *J. Mater. Process. Technol.,* Vol. 200, pp.283–287, 2008.

[2] S. Debin, L. Yan, L. Ping, and X. Yi, “Experimental study on process of cold-power spinning of Ti-15-3 alloy”, *J. Mater. Process. Technol.*, Vol. 115, Pp. 380–383, 2001.

[3] J.W. Park, “Analysis of tube spinning processes by the upper-boundstream function method”, *Jounal of materials processing Technology*, 66, pp. 195-203, 1997.

[4] M. Jahazi, and G. Ebrahimi, “The influence of flow forming parameters and microstructure on the quality of D 6ac steel”, *J. Mater. Process. Technol*., 103, 362–366, 2000.

[5] J. Shu-yong, Multi-pass spinning of thin-walled tubular with longitudinal inner ribs”, *Trans. Of nonferrous metals society of China*, 19, pp. 215-221, 2009.

[6] S. Kalpakjian, and S. Rajagopal, “Spinning of Tubes: A Review,” *J. Applied Metalworking, American Society for Metals*, Vol. 2, No. 3, pp. 211-223, 1982.

[7] M. Frnčík, J. Šugárová, P. Šugár and B. Ludrovcová, “The effect of conventional metal spinning parameters on the spun-part wall thickness variation”, *IOP Conference Series Materials Science and Engineering*, vol. 448, pp.012-017, 2018.

[8] M. Shinde, “Metal Forming By Sheet Metal Spinning Enhancement of Mechanical Properties and Parameter of Metal Spinning”, *International journal of Engineering development and research*, voL. 2, No. 2, pp. 1352-1357, 2014.

[9] M.H. Parsa, A.M.A. Pazooki, and M. Nili Ahmadabadi, “Flow-forming and flow formability simulation”, *Int. J. Adv. Manuf. Technol*., 42, pp.463–473, 2009.

[10] P. Sugar, “Analysis of the effect of process parameters on part wall thickness variation in conventional metal spinning of Cr-Mn austenitic stainless steels”, *Journal of mechanical Engineering*, pp. 171-178, 2015.

[11] P. Šugár, J. Šugárová, and J. Petrovič, “Analysis of the effect of process parameters on part wall thickness variation in conventional metal spinning of Cr-Mn austenitic stainless steels”, *Journal of Mechanical Engineering*, vol. 62, pp.171-178, 2016.

[12] K.M. Rajan, and K. Narsimhan, “An investigation of the development of defects during flow forming of high strength thin wall steel tubes”, ASM. J. Pract. Failure. Anal., 1(5), 69–76, 2001.

[13] S. Kamboj, “Analysis the effects of different types of on metal spinning process”, *International Journal of Research in Engineering and Technology*, vol. 3, pp. 64-70, 2014.

[14] S. Thanapat, and D. Surangsee, “Spinning Process Design Using Finite Element Analysis and Taguchi Method”, *Procedia Engineering*, vol. 207, pp.1713-1718, 2017.

[15] C.C. Wong, J. Lin, and T.A. Dean, “Effects of roller path and geometry on the flow forming of solid cylindrical components”. *J. Mater. Process. Technol.,* 167, 344–353, 2005.

[16] C.C. Wong, J. Lin, and T.A. Dean, “Incremental forming of solid cylindrical components using flow forming principles”, *J. Mater. Process. Technol.,* Vol. 153-154, 60–66, 2004.

[17] C.C. Wong, T.A. Dean, and J. Lin, “A review of spinning, shear forming and flow forming processes,” *International Journal of Machine Tools & Manufacture*, 23, pp. 1419–1435, 2003.