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Microstructure Distribution Characteristics of High-Strength Aluminum Alloy Thin-Walled Tubes during Multi-Passes Hot Power Backward Spinning Process

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Abstract

The microstructure of the thin-walled tubes with high-strength aluminum alloy determines their final forming quality and performance. This type of tube can be manufactured by multi-pass hot power backward spinning process as it can eliminate casting defects, refine microstructure and improve the plasticity of the tube. To analyze the microstructure distribution characteristics of the tube during the spinning process, a 3D coupled thermo-mechanical FE model coupled with the microstructure evolution model of the process was established under the ABAQUS environment. The microstructure evolution characteristics and laws of the tube for the whole spinning process were analyzed. The results show that the dynamic recrystallization is mainly produced in the spinning deformation zone and root area of the tube. In the first pass, the dynamic recrystallization phenomenon is not obvious in the tube. With the pass increasing, the trend of dynamic recrystallization volume percentage gradually increases and extends from the outer surface of the tube to the inner surface. The fine-grained area shows the states of concentration, dispersion, and re-concentration as the pass number increases.

Keywords

Cast High-Strength Aluminum Alloy Tube, Multi-Pass Hot Power Backward Spinning, FE Simulation, Microstructure Evolution

1. Introduction

High-strength aluminum alloy thin-walled tubes (HSATs) with the merits of high strength, excellent corrosion, and light weight, are widely used in aerospace, aviation, and weapons [1]. This type of tube can be manufactured by the multi-pass hot power backward spinning (MPHPBS) process because it can eliminate casting defects, refine microstructure and improve the plasticity of the tube [2]. However, MPHPBS is a complex and unsteady state-forming process coupled with multi-field, multi-dies, and multi-factor characters [3]. During the spinning process, the material of the tube experienced complex uneven deformation and microstructure evolution [4]. And this complicates microstructure evolution affects the tube forming quality as well as the performance [5]. Therefore, it is of great significance to study the microstructure evolution characteristics of the whole hot power backward process [6].

In this paper, microstructure distribution characteristics of high-strength aluminum alloy thin-walled tubes in the multi-passes hot power backward spinning process are analyzed based on the FE model. The achievements can provide a basis for the microstructure optimization, performance prediction, and control of the power spinning process of tubes [7].

2. Research Program

2.1. FE Model

A 3D coupled thermo-mechanical FE model (see **Figure 1**) coupled with a microstructure evolution model for the MPHPBS process of 7075 aluminum alloy tubes was established under the ABAQUS environment based on the solution of the key FE modeling technologies, such as geometric modeling, material modeling and loading boundary conditions [1].

2.2. Material Property

In this paper, the raw material used in the simulation is a semi-continuous cast

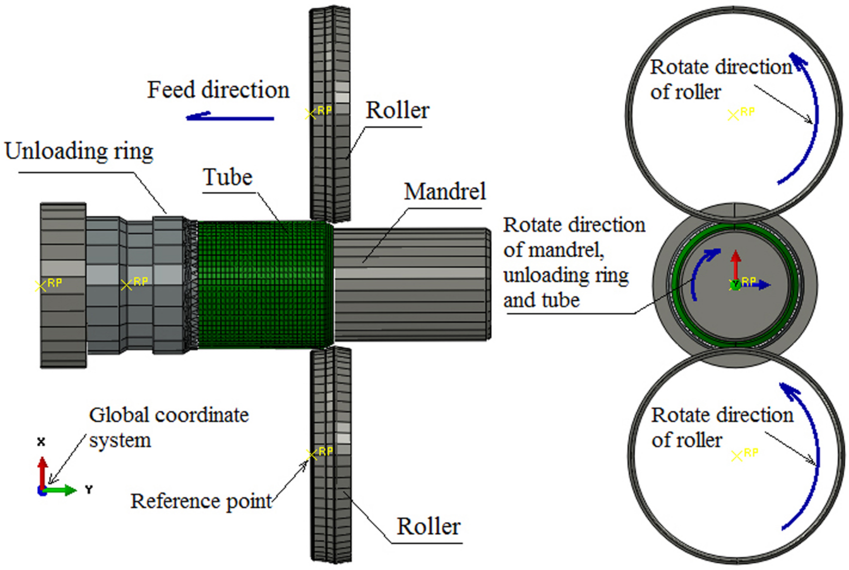


Figure 1. The 3D elastoplastic finite element model of the multi-pass hot power backward of 7075 aluminum alloy tubes.

tube of 7075 aluminum alloy. The mechanical properties are seen in **Table 1**, and the Fields-Backofen model is used to represent the relationship (see Equation (1)) among the stress, strain and temperature during the MPHPBS process [8].

$$\sigma = 13747.9386\varepsilon^{0.0599}\dot{\varepsilon}^{0.1091}\exp\left(-0.007T - 0.2498\varepsilon\right) \tag{1}$$

2.3. Characteristic Cross-Section

To analyze the microstructure distribution characteristics in circumferential direction of the spun tube, along the axial direction of the tubes from the root to the end, the seven characteristic sections of the equal proportion sections, such as S0, S1, S2, S3, S4, S5, and S6 (as shown in **Figure 2**) are selected. To analyze the microstructure distribution characteristics along the axial direction of the spun tube with different spinning passes, the axial symmetry section are selected (as shown in **Figure 3**) [9].

3. Results and Discussion

3.1. Dynamic Recrystallization Volume Percentage (RVF) Distribution Characteristics

From the **Figure 4**, it can be seen that under different spinning passes, dynamic

Table 1. Mechanical properties of as-cast 7075 aluminum alloy.

Parameter	Value
Poisson's ration	0.33
Density (Kg/mm)	2780
Elastic (MPa)	$E = 715.56835T^3 - 522015.09556T^2 - 9.67285\times10^6T + 7.13247\times10^{10}$

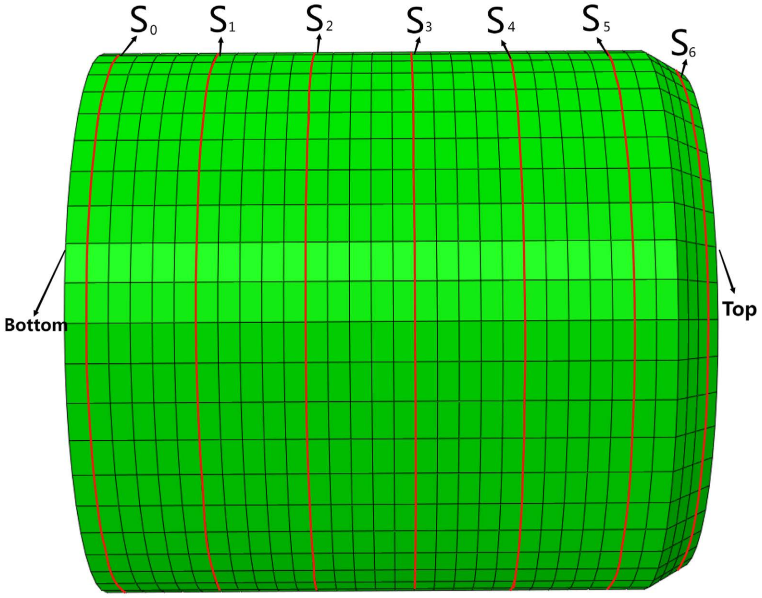


Figure 2. Characteristic sections along the axial direction of the tubes.

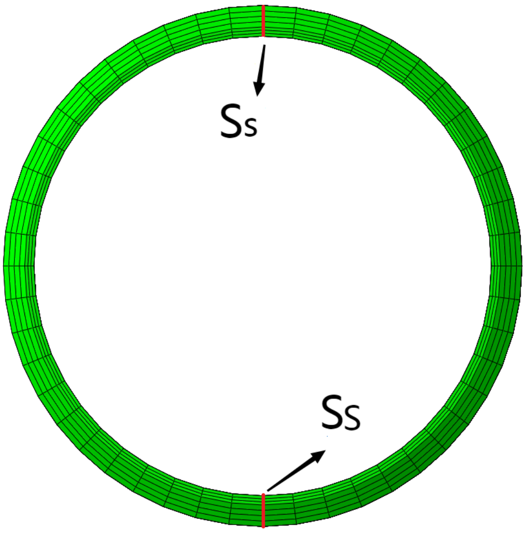


Figure 3. Axisymmetric section of the tubes.

recrystallization only occurs in the spinning deformation zone, while there is almost no dynamic recrystallization phenomenon in the unspun area. With the increase of spinning passes, the dynamic recrystallization trend of deformation areas of the tubes gradually increased. Beside the first spinning pass, the dynamic recrystallization phenomenon is obvious in all other passes. In addition, with the increase of spinning process, dynamic recrystallization is occurred in the outer surface of the tube firstly, and then extended to the inner surface. But, the dynamic recrystallization in the inner surface has become a main zone.

3.2. Dynamic Recrystallization Grain Sizes (RGSs) Distribution Characteristics

Dynamic recrystallization grain sizes (RGSs) distribution characteristics are shown in **Figure 5**. From **Figure 5**, it can be seen that under different spinning passes, larger areas of dynamic RGS mainly distributes in the spinning deformation zone and near the root area of the tube. With spinning process progressing in the first spinning pass, large areas of dynamic RGS mainly distributes in the outer surface of the tube and in this area the dynamic RGS uniformly distributes; while in the inner surface, the areas of dynamic RGS is smaller and non-uniform distributed. With the increase of spinning process, dynamic recrystallization is occurred in the outer surface of the tube firstly, and then extended to the inner surface. The inner surface recrystallization area and grain size gradually increase. And the dynamic recrystallization in the inner surface has become a main zone.

3.3. Dynamic Average Grain Sizes (AGSs) Distribution Characteristics

Dynamic average grain sizes (AGSs) distribution characteristics are shown in **Figure 6**.

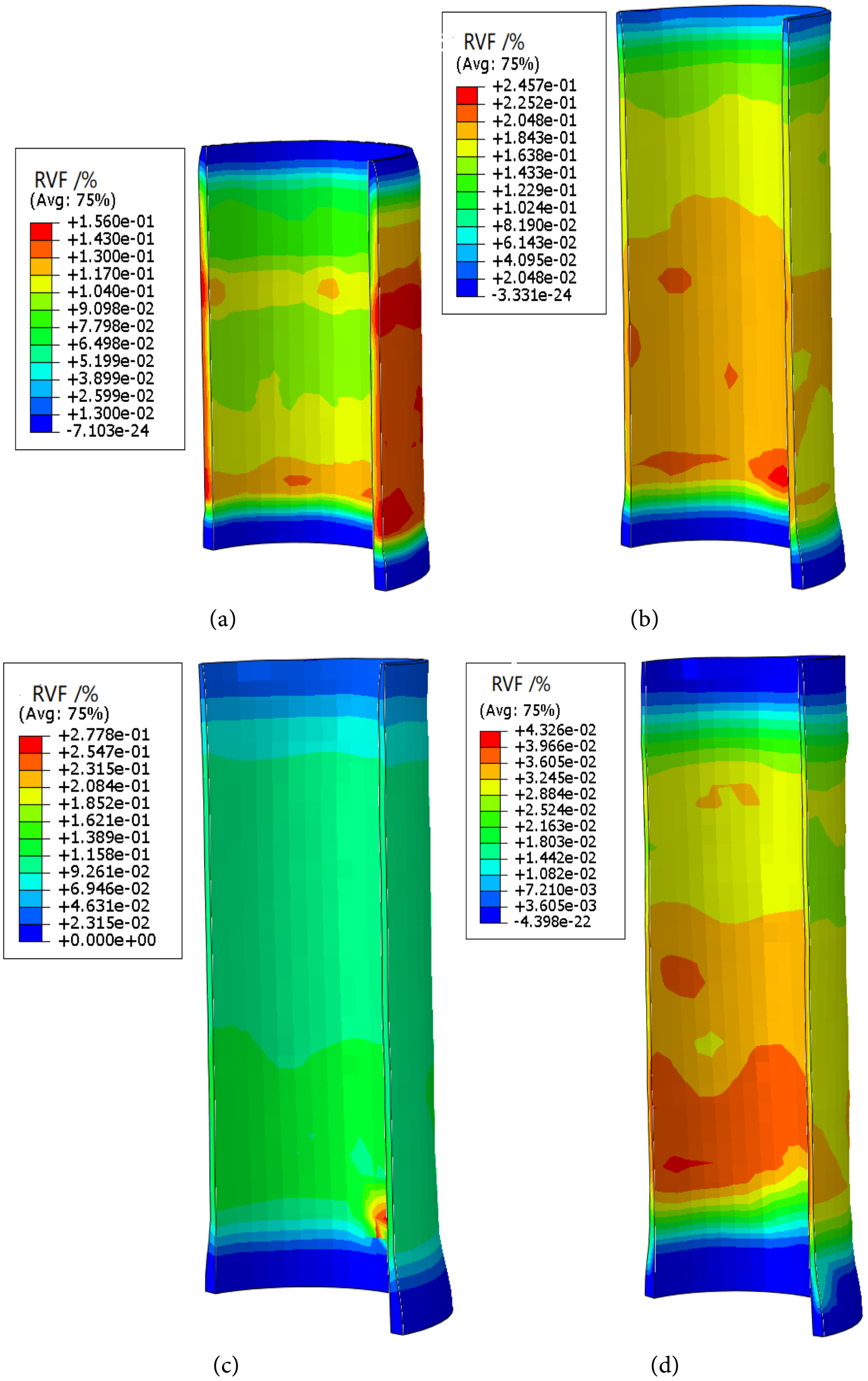
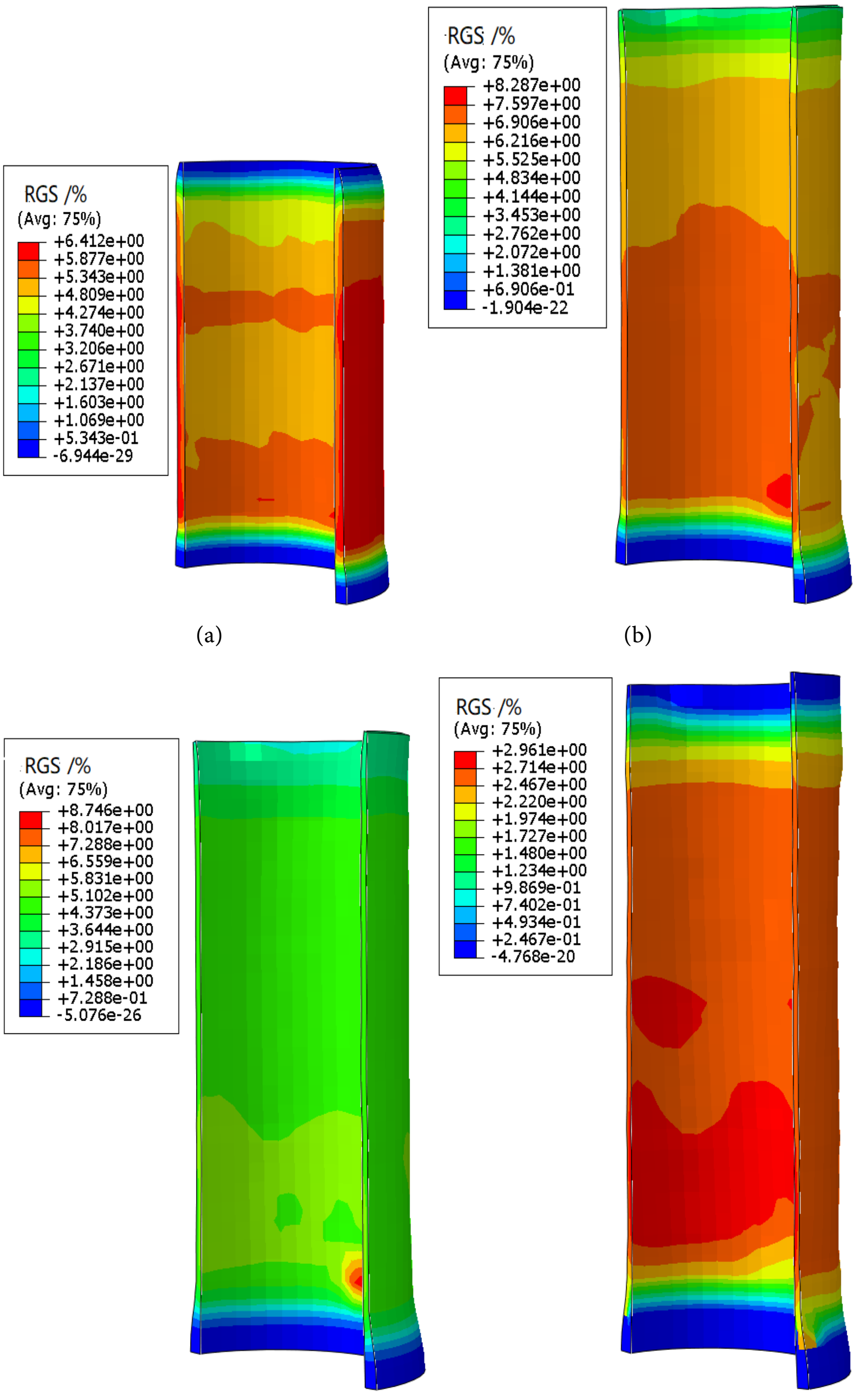


Figure 4. The distribution of RVF in deferent spinning passes: (a) Pass 1; (b) Pass 2; (c) Pass 3; (d) Pass 4.

From **Figure 6**, it can be seen that under different spinning passes, the dynamic AGS at the end and the root of the tube are the large. The fine grain zone is mainly distributed in the spinning deformation large area and near the root zone of the tube. The fine grain zone is concentrated in the first, second and fourth passes and dispersed in the third pass. With the increase of spinning passes, the fine grain zone is distributed in the outer surface of the tube firstly, then extended



(a) (b)

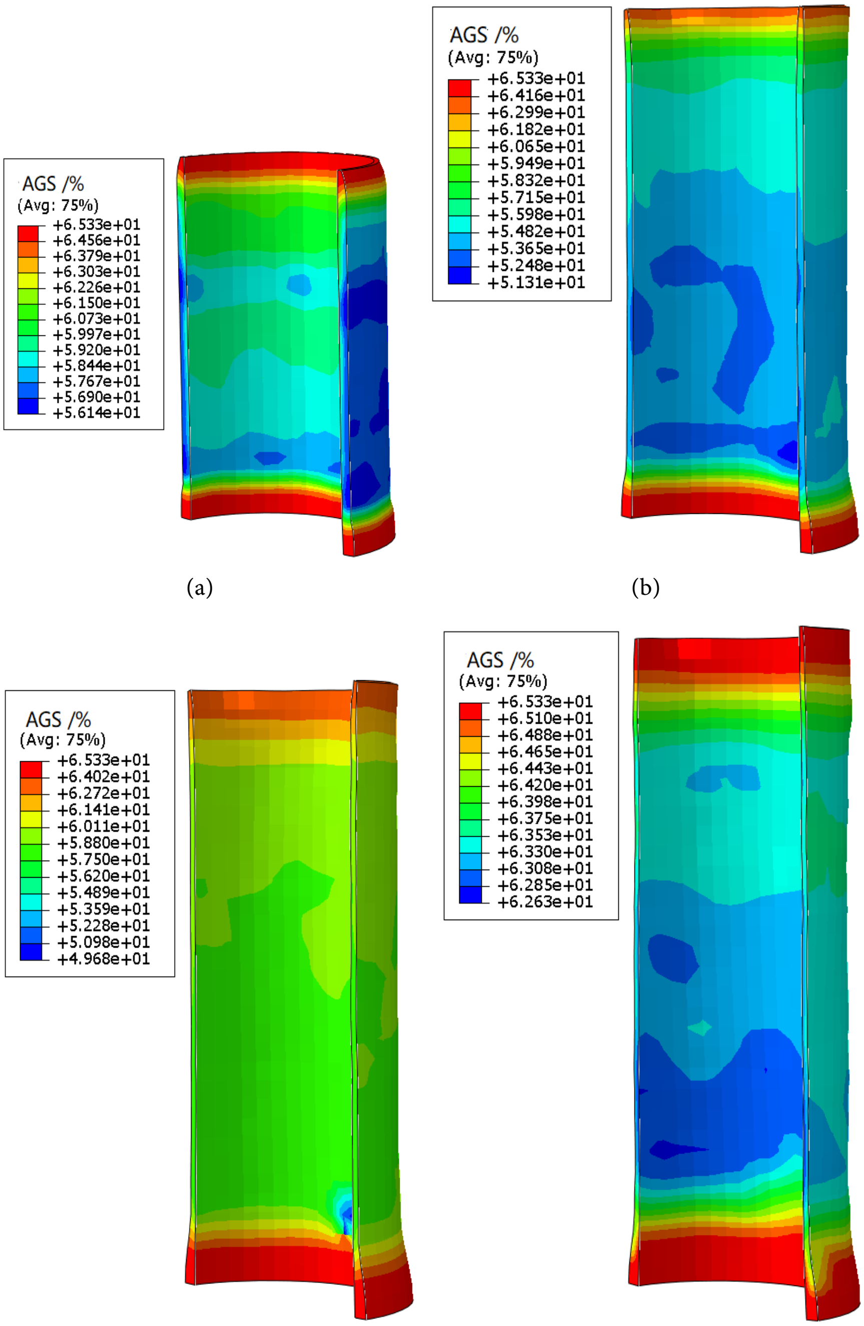
(c) (d)

Figure 5. The distribution of dynamic RGS in deferent spinning passes: (a) Pass 1; (b) Pass 2; (c) Pass 3; (d) Pass 4.

to the inner surface, and finally the inside surface is a main surface.

4. Conclusion

The dynamic AGS and the dynamic RGS are mainly distributed in the spinning



(a) (b)

(c) (d)

Figure 6. The distribution of AGS in deferent spinning passes: (a) Pass 1; (b) Pass 2; (c) Pass 3; (d) Pass 4.

deformation zone and near the root area of the tube. The dynamic RVF occurs in the spinning deformation zone. And the dynamic RVF, the dynamic RGS, and the fine grain zone are extended from the outer surface to the inner surface and finally, the inner surface is the main surface. With the increase of passes, the dynamic RVF and the dynamic RGS gradually increase. The fine grain zone shows a trend from concentration to dispersion and then to concentration. And the fine grain zone gradually transfers to the root of the tube.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Zhang, R.Y., Yu, H. and Zhao, G.Y. (2019) Role of Friction in Prediction and Control Ellipticity of High-Strength Casting Aluminum Alloy Tube during Hot Power Backward Spinning. *The International Journal of Advanced Manufacturing Technology*, **102**, 2709-2720. https://doi.org/10.1007/s00170-019-03336-7

[2] Zhao, G.Y., Lu, C.J., Zhang, R.Y., Guo, Z.H. and Zhang, M.Y. (2017) Uneven Plastic Deformation Behavior of High-Strength Cast Aluminum Alloy Tube in Multi-Pass Hot Power Backward Spinning. *The International Journal of Advanced Manufacturing Technology*, **88**, 907-921. https://doi.org/10.1007/s00170-016-8800-4

[3] Gao, P.F., Yu, C., Fu, M.W., Xing, L., Zhan, M. and Guo, J. (2022) Formability Enhancement in Hot Spinning of Titanium Alloy Thin-Walled Tube via Prediction and Control of Ductile Fracture. *Chinese Journal of Aeronautics*, **35**, 320-331. https://doi.org/10.1016/j.cja.2021.01.002

[4] Yuan, S., Xia, Q.X., Cheng, X.Q. and Xiao, G.F. (2022) Simulation Study on the Texture Evolution Mechanism of Magnesium Alloy Cylindrical Parts with Inner Ribs during Hot Power Spinning. *IOP Conference Series: Materials Science and Engineering*, **1270**, Article ID: 012081. https://doi.org/10.1088/1757-899X/1270/1/012081

[5] Huang, K., Yi, Y.P., Huang, S.Q., He, H.L., Dong, F., Jia, Y.Z. and Yu, W.W. (2023) Cryogenic Die-Less Spinning of Aluminum Alloy Thin-Walled Curved Components and Microstructure Evolution. *Journal of Manufacturing Processes*, **92**, 32-41. https://doi.org/10.1016/j.jmapro.2023.02.045

[6] Xia, Q.X., Long, J.C., Zhu, N.Y. and Xiao, G.F. (2019) Research on the Microstructure Evolution of Ni-Based Superalloy Cylindrical Parts during Hot Power Spinning. *Advances in Manufacturing*, **7**, 52-63. https://doi.org/10.1007/s40436-018-0242-9

[7] Kang, C.S. (2018) Finite Element Numerical Simulation of Microstructure Evolution of Hot Power Backward of Cast 7075 Aluminum Alloy Tubes. Ph.D. Thesis, Nanchang Hangkong University, Nanchang, 52-57.

[8] Zhang, R.Y. (2019) Study on Microstructure Evolution of As Cast High-Strength Aluminum Alloy Tubes during Multi-Pass Hot Backward Spinning. Ph.D. Thesis, Chinese Aeronautical Establishment, Beijing, 103-107.

[9] Liu, Y.L., Shu, X.D., Cen, Z.W., Li, Z.X. and Ye, B.H. (2021) Effects of Process Parameters on Surface Straightness of Variable-Section Conical Parts during Hot Power Spinning. *Applied Sciences*, **11**, Article 8187. https://doi.org/10.3390/app11178187