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RESEARCH ON THE DYNAMIC RECRYSTALLIZATION LAW OF CROSS WEDGE ROLLING(CWR) ASYMMETRIC HOLLOW SHAFT

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To improve mechanical properties of asymmetrical hollow shafts parts, the dynamic recrystallization of asymmetrical hollow shaft can be obtained by cross wedge rolling (CWR) technology. The Finite element model (FEM) is established using the DEFORM-3D software, the distribution of the dynamic recrystallization volume fraction is illustrated, and the law of average grain size distribution is analyzed. The microscopy results indicate that the grain size at the central area of cross-section is larger than that at lateral area, and the grain of the central part can be obviously refined, the whole microstructure homogeneity is improved, which have provided theoretical foundation for further improving the quality and mechanical properties of CWR asymmetrical hollow shafts parts.

Key words: cross wedge rolling, asymmetric rolling, dynamic recrystallization, FEM, metalography

INTRODUCTION

Cross wedge rolling (CWR) is used to form axisymmetric parts and shafts that offer a great number of advantages, such as high production yield, effective material utilization, and eco-friendliness of the process [1]. Dynamic recrystallization is one of microstructure evolution in the rolling process, which have provided theoretical foundation for improving the quality and mechanical properties. Some domestic microstructure research had investigated in the process of thermo-plastic forming. Begin from 2002, the group of Du fengshan from Yanshan university had researched on microstructure of hollow part during hot deformation by 3-roll CWR[2]. The microstructure evolution law of CWR asymmetric shaft-parts based on parity wedge had researched by Gong wenwei[3]. But the shaft they studied was the Solid shaft. The deformation and dynamic recrystallization of 42CrMo crankshaft in pre-forming process was simulated by Zhou J, using the coupled thermo-mechanical analysis method of rigid viscoplastic finite element and the evolution of dynamic recrystallization[4].

The following sections will present our study on the law of CWR asymmetric hollow shaft during dynamic recrystallization. This research were investigated from two aspects,that is the distribution character of dynamic recrystallization volume fraction in CWR asymmetrical hollow shaft, another one is the character of average grain size distribution.

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THE DESCRIPTIONOF DYNAMIC RECRYSTALLIZATION MODEL

The product dimension is shown as Figure 1.

The activated criterion

ε_c reflects the activation of dynamic recrystallization. The activated criterion of dynamic recrystallization can be shown as follows [5]:

$$\varepsilon_p = 3,8 \times 10^{-4} d_0^{0,43201} \dot{\varepsilon}^{0,2106} \exp[51915 / RT] \quad (1)$$

$$\varepsilon_C = 0,696 \varepsilon_P \quad (2)$$

Where, ε_p and ε_c are the peak strain and the critical strainof the dynamic recrystallization, respectively.

The kinematicalequation

The equation presented as follow is described the phoronomics of dynamic recrystallization using avrami equation, that is [5]:

$$X_{drex} = 1 - \exp[-\beta_d (\frac{\varepsilon - \varepsilon_c}{\varepsilon_{0,5}})^2] \quad (3)$$

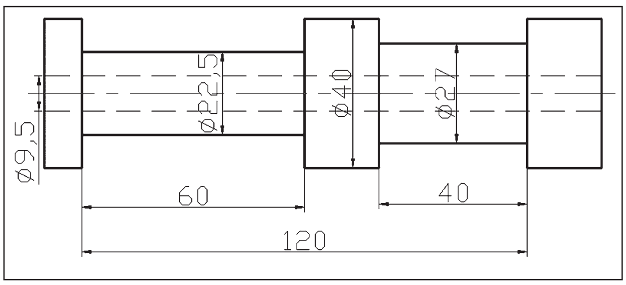

Figure 1 The product drawing of CWR asymmetrical hollow shaft

$$\varepsilon_{0,5} = 5{,}048\times10^{-3} d_0^{\,0,4772}\dot{\varepsilon}^{\,0,1258}\exp[26128/RT] \quad (4)$$

$$\beta_d = 0{,}23\ \dot{\varepsilon}^{\,0,21213}\exp[29771/(RT)] \quad (5)$$

Where, X_{drex} and β_d are the volume fraction and the influence coefficient of dynamic recrystallization, respectively; $\varepsilon_{0,5}$ is the strain with 50% X_{drex}.

The grain size model

The grain size is obtained by following equation [5]:

$$d_{rex} = 13{,}41 d_0 \varepsilon^{\,0,16085}\dot{\varepsilon}^{\,-0,2345}\exp[-42327{,}5/(RT)] \quad (6)$$

Where, d_{rex} is the grain size of dynamic recrystallization.

THE FEM MODELOF CWR ASYMMETRICAL HOLLOW SHAFTS

The forming angle of left wedge $\alpha_1$is25,8°, the forming angle of right wedgeα_2 is 34,2°, the stretching angle of left wedge β_1 is 8,26°, the stretching angle of right wedge β_2 is 8,26°.The finite element model is established as shown in Figure 2.

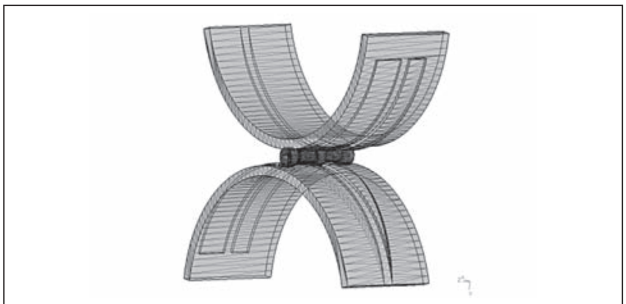

Figure 2 FEM of CWR asymmetrical hollow shaft

FEM ANALYSIS RESULTS

The distribution character of dynamic recrystallization volume fraction in CWR asymmetrical hollow shaft

Figure 3 shows that the distribution of dynamic recrystallization volumetric fraction under different steps of stretching stage. It can be seen from the step 129 that within the scope of longitudinal section, the dynamic recrystallization volumetric fraction of step is declining from the direction of two sides to the central section. The step 208 shows that in the same cross section, the dynamic recrystallization volumetric fraction of step is progressively decreasing from the core to the surface; In the central section of step, the core is first to have complete dynamic recrystallization. This is because axial flow is occurred in step metal under the traction of axial force, while the metal in the formed area will hinder the axial flow of step metal under the influence of radial pressure. Obviously, radial force of surface metal in the forming area is greater than that of core metal, its hindrance of axial flow to step metal is higher than that

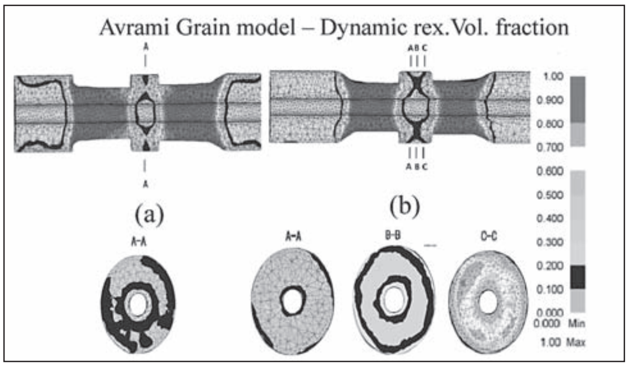

Figure 3 Distribution of dynamic recrys-tallization volumetric fraction in stretching stage, they should be listed as: (a) ynamic rex.vol. fraction of the 230 step;(b) dynamic rex. vol. fraction of the 315 step

of core metal. Therefore, the axial flow capacity of core metal is better than that of surface metal, in the same cross section, core metal is more rapid to reach the critical strain of dynamic recrystallization than that of surface metal. Besides, due the effect of plastic functional transformation and the heat exchange of surface metal and module, the temperature in the heart of step is higher than thing from the core to the surface.

The character of average grain size distribution in CWR asymmetrical hollow shaft

It can be seen from Figure 4 that the rolled part under high-temperature produce large deformation, and the parts are entirety refined, and most of the average grain size after dynamic recrystallization has reached to 9,75~30,25μm. In terms of average grain size distribution in the forming area, the refining degree of grain size in left forming area is higher than that of the right forming area, the grain size of core is bigger than that of the outside forming area. It is because that the percentage of reduction of area in the right forming area is high, strain capacity is great, and its dynamic recrystallization degree is higher than the right forming area,then the microstructure uniformity of CWR asymmetrical hollow shaft parts is increased.

MICROSCOPY EXPERIMENT RESULTS AND DISCUSSION

The distribution of the microstructural evolution during dynamic recrystallization in the different sectionwereinvestigated at a deformation degree of 15 % and strain rate 0,1s^{-1}, which is showed as Figure5(a)-(c). The sizes of recrystallization austenite grain size have been measured by metallographic methods. The values can be found from Table 1 in detail.

Known from the Table 1, the average grain size of the section A-A has reached to 18,40 *um*, the grain of the position 1 is smaller than that of the position 3, it means that the grain size of core is bigger than that of

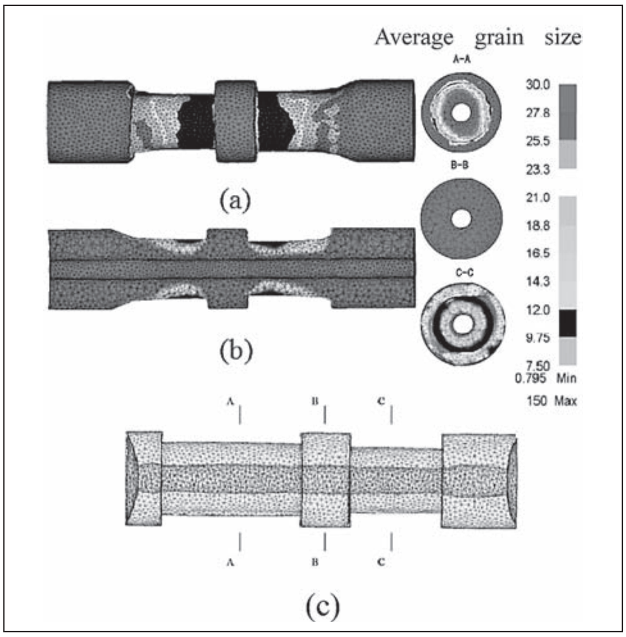

Figure 4 The distribution of average grain size in CWR asymmetrical hollow shaft, they should be listed as: (a) The distribution of average grain size in the surface of work piece; (b) the distribution of average grain in the forming area and step; (c) the distribution of average grain size in the longitudinal section

the surface forming area. So as to the section C-C, the average grain size of the section C-C has reached to 18,84 *um*, the grain size rule is same to the section of A-A, the grain size became bigger from the outside to the inside along the radial section. The grain size of the section C-C is smaller than that of the section A-A. The average grain size of the section B-B has reached to 27,74 *um*, and most of the grain size is bigger than that of the other two sections.

Table 1 **The value of grain size /*um***

Section	Different position			
	1	2	3	The average grain size
A-A	10,68	18,88	25,63	18,40
B-B	24,82	26,82	31,59	27,74
C-C	10,66	14,26	31,59	18,84

CONCLUSIONS

(1) The route of dynamic recrystallization of CWR asymmetrical hollow shaft parts: In the view of forming area, the route for dynamic recrystallization is “from the outside to the inside” and “from the midsection to the two ends”; In the view of step, the moving route of dynamic recrystallization of step is “permeating to the midsection” and “from inside to outside”.

(2) Microstructural evolution in knifing zone, surface metal deformation reaches the critical deformation, and occurring dynamic recrystallization softening, the original grain is smaller, which couldn’t only be

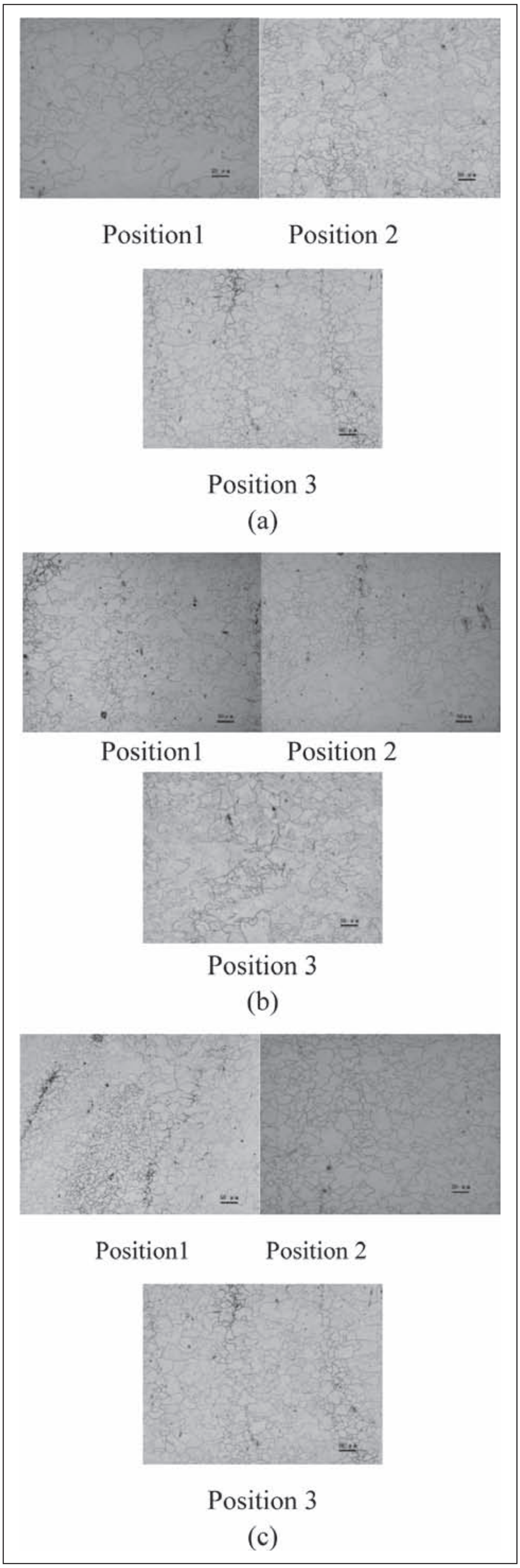

Figure 5 Typical dynamically recrystallization grains of three section ofthe deformed asymmetrical hollow shaft.

emerged in the area of dynamic recrystallization, recrystallization volume percentage of the dynamic recrystallization almost is zero. Microstructural evolution in stretching zone, the average grain size in the deformation zone is small, and the average grain is still large in the deformation area.

(3) The grain size at the central area of cross-section is larger than that at lateral area. The main reason is that the reduction rate of section is lower. The lower reduction rate will not make plastic deformation penetrate from surface into center.

(4) The relational expression in this paper was used to predict the recrystallization softening and the grain size of austenite. It is capable of provide theoretical foundation for further improving the quality and mechanical properties of CWR asymmetrical hollow shafts parts.

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Note: The professional translator for the English language is Qian Qian Yan, Zhejiang, China