Experimental Study of Recrystallization for C-Mn extruded Workpiece

Baojian Yang¹, Li Jiang¹, Huijun Li², Yonghua Zhong¹ and Jianhua Tang¹

¹Department of intelligent manufacturing, Wuyi University, Jiangmen, China
²Department of engineering, Wolong Univeristy, Australia
Email: kurt.yang@163.com

Abstract. Recrystallization is a key step while conducting the composite process of severe extruding and heating treatment for fabricating the ultrafine-grained parts, however, the heating temperature plays a vital role that it directly effects the metallographic structure of extruded workpiece. In order to reveal the effects of heating temperature on metallographic structure of the extruded workpieces, three kinds of samples with different reduction ratio were put into the heating furnace when the temperature in furnace is over the recovery temperature of C-Mn extruded workpiece (about 450 °C), that is to shorten the temperature-rising time, thus the nucleation rate was increased simultaneously by doing so. During the heating process, the time-constant & temperature-varying together with time-varying & temperature-constant experimental scheme were adopted for different samples. Finally by measuring the hardness and analyzing the microstructures of C-Mn extruded workpiece, it can be concluded that fully recrystallization occurs in No.3 extruded workpiece with the condition of heating for 1 hour at 580 °C and cooled in the furnace, its average size is about 1 um.

1. Introduction
Severe extruding is a kind of methods for huge plastic deformation. It refines grains by exerting enormous forming force on the surface of workpiece via extruding wheels, so as to conduct a sufficiently large plastic deformation in the material as a whole [1, 2]. During the severe extruding process of blank, the working power of extruding wheels was dissipated by both internal and external material of the blank. In the internal factors of energy consumption, most of the working power was changed into deformation energy, which formed the cold deformation texture later. Nevertheless, about 2% - 15% of the energy reversed in internal section of the deformation metal, which caused the crystal lattice defects, such as strain hardening (higher hardness and strength, lower plasticity and toughness), anisotropic phenomenon in both mechanical and physical [3, 4]. Finally, it caused the deformed metal became a metastable state in thermodynamics, which will brought a certain difficulties to the preparation of ultra-fine crystal parts. However, recrystallization after severe extruding can eliminate the metastable state during the composite process, and also it can refine the grains greatly.

2. Experiment Scheme
First of all, labelled three samples of different thinning rate (70% for sample 1, 80% for sample 2, 90% for sample 3) as a segment, then put them into the furnace while its temperature is over 450 °C, and kept for 1 hour at different temperatures (as shown in Fig.1), then cool to room temperature. Secondly, kept another group of samples at the temperature obtained from above for 0.5 hour, 1 hour, 1.5 hour and 2 hour respectively, then cooled them to room temperature (as shown in Fig.2). Moreover, the hardness and microstructure were observed in order to acquire the proper recrystallization temperature and soaking time.
3. Experimental Results

3.1. Influence of Temperature on Recrystallization
Assume that the decreases rate of metal hardness due to the increasing annealing temperature is of consistent with the nucleation and growth rate of the material[5,6]. The faster the metal hardness reduced, the bigger the corresponding nucleation and growth rate.

![Figure 1. Curve of hardness-temperature](image)

Figure 1 shows the relationship between the hardness of different samples and annealing temperature. With the temperature increases, the hardness value drops sharply although the thinning rate of samples varied among 70%, 80% and 90%. After reaching a certain temperature, such as hardness value basically remain unchanged. In figure 1, the annealing temperature sample hardness value changed a little before 550 °C, but in 560-600 °C period, the hardness value began to drop dramatically, and it basically become stable at 620 °C or so. The organization is mainly the phase of recovery before 550 °C, and in 560 ~ 600 °C period, the recrystallization happens, that is the new grain nucleation and growth. When the temperature higher than 600 °C, it is mainly the grain growing up process after recrystallization.

3.2. Influence of Soaking Time on Recrystallization
It can be seen from figure 2 that the sample hardness value changes little when the annealing temperature was set to 560 °C, and the vickers hardness value remains at about 210 after 2 hours annealing, which is quite similar to that of samples without annealing treatment. So it could draw a conclusion that no recrystallization happens when the annealing temperature setting to 560 °C. When annealing temperature setting to 580 °C, and keeping for more than half an hour, the sample hardness value falls faster and faster, it shows that the recrystallization is under way, and then sample hardness value is falling slowly to around 170. When the annealing temperature setting to 600 °C and heat preservation after half an hour, sample hardness value decreased rapidly, however, with soaking time extended, the hardness is slowing down gradually. It shows that recrystallization is still going but very slowly. When the soaking time is of 1.5 hour, rigidity remains the same, and it shows that the recrystallization process was basically completed.
Figure 2. Curve of hardness-soaking time

From figure 2, it can be seen when the temperature change under the condition of temperature over 580 °C, insulation 0.5 h, the biggest reduction ratio of 3# sample hardness decreased fastest, 2# sample and 1# sample are the slowest. This is mainly because with the increase of reduction ratio, internal sample distortion energy increases, the dislocation density increases, the recrystallization driving force also increase, and thus accelerate the recrystallization process[7]. Therefore, to improve the thickness reduction ratio during C - Mn steel extruding, is advantageous to the recrystallization process.

From above, when the annealing temperature exceeds recrystallization temperature (580 °C), extended soaking time does little to promote the recrystallization process, but increasing both the annealing temperature and reduction ratio can accelerate the recrystallization process greatly.

3.3. Metallographic Structure Observation

In order to verify the accuracy of the recrystallization temperature got by hardness test, the microstructure test and SEM analyses were conducted. Figure 3 shows the microstructure pictures of 2# sample under the condition that temperature constant & time varying. Figure 4 shows the microstructure of 2# sample in the extruding process and the evolution in the process of annealing.
4. Summary
Through the experimental research of C-Mn steel recrystallization, it can be conclude as follows:
(1) The heating temperature is one of the major factors of static recrystallization. New grain
nucleation and growth mainly happens while the temperature among 560 to 600 °C.

(2) With the increase of wall thickness reduction ratio, internal distortion of the sample can improve ferrite grain refinement, and the grain boundary pinning and hinder the extension function to a certain extent which is conducive to further refine ferrite grain.

(3) When the annealing temperature above the recrystallization temperature, extending the time of heat preservation is meaningless to promote the recrystallization process, but increasing the wall thickness reduction ratio can also accelerate the recrystallization process.

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6. References
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