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Study on austenite recrystallization softening behavior of GCr15 steel

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Abstract. The double-pass hot compression tests were carried out by MMS-300 thermal simulator. The effects of deformation temperature, deformation amount, strain rate, and austenite grain size on sub-dynamic recrystallization and static recrystallization of GCr15 bearing steel were studied systematically. Based on this, the microstructure controlling of invested steel wire rods during rolling was discussed in this paper, which can provide a basis for the reasonable determination of heating and deformation in the actual production process.

1. Introduction

Some of dynamic recrystallized austenite will undergo sub-dynamic recovery and sub-dynamic recrystallization, and others without dynamic recrystallization will undergo static recovery and static recrystallization in the gap time after thermal deformation. The occurrence and development of these phenomena will directly affect the internal quality of the workpiece and greatly affect the mechanical properties of the material [1-2]. Therefore, it is necessary to study the recrystallization rule in the thermoforming gap time of the material by thermal simulation method to adjust the austenite structure state, and then obtain the required structure and properties of the material [3-5].

2. Experimental materials and methods

The investigated material is GCr15 bearing steel, and its main chemical composition (mass fraction, %) is: C 1.0, Cr 1.46, Mn 0.31, Si 0.24, S 0.05, P 0.007, Ti 0.0023, balance Fe. The hot compressed specimens were processed into a cylinder of $\varnothing 8 \text{ mm} \times 15 \text{ mm}$, and the compression test was carried out on a MMS-300 thermal simulator. Firstly, the sample is heated to austenitizing temperature at a rate of 10°C/s , holding for 3 min, then cooled to a deformation temperature at 5°C/s , kept for 10s to eliminate the temperature gradient inside the sample. Then, the first compression is performed, and the second compression is performed after a certain time, which the deformation condition is the same as that of the first time. The specific test parameters are as follows:

a. The experimental program of sub-dynamic recrystallization. The samples were respectively compressed at 950°C , 1000°C and 1050°C considering the influence of deformation temperature, the strain rate was fixed to 0.1s-1, the deformation amount was 0.357, and the interval time was 1, 5, 10, 50 and 100s. The compression was performed at the strain rates of 0.01s-1, 0.05s-1 and 0.1s-1, respectively,



considering the influence of strain rate, the deformation temperature was 950 °C, and the deformation amount and the interval time were the same as before. The compression was respectively performed at the true strain of 0.223, 0.357 and 0.511 considering the influence of deformation amount, and the deformation temperature, deformation amount and the interval time were the same as before. Considering the influence of the initial grain size, the samples were first heated to different austenitizing temperatures of 1000°C 1100°C and 1150°C to obtain different initial austenite grain sizes of 237.2 μm, 356.54 μm and 520.71 μm respectively, then a two-pass compression test with the same parameters as before was performed.

b. The experimental program of static recrystallization. The samples were respectively compressed at 750°C, 800°C, 850°C, 900°C and 950°C considering the influence of deformation temperature, the strain rate was fixed to 5s-1, the deformation amount was 0.223, and the interval time was 1, 5, 10, 50 and 200s. The compression was performed at the strain rates of 1s-1, 5s-1 and 10s-1, respectively, considering the influence of strain rate, the deformation temperature was 900°C, and the deformation amount and the interval time were the same as before. The compression was respectively performed at the true strain of 0.105, 0.223 and 0.357 considering the influence of deformation amount, and the deformation temperature, deformation amount and the interval time were the same as before. Considering the influence of the initial grain size, the samples were first heated to different austenitizing temperatures of 1050°C, 1150°C and 1200°C to obtain different initial austenite grain sizes of 292.68μm, 520.71μm and 532.44μm respectively, then a two-pass compression test with the same parameters as before was performed.

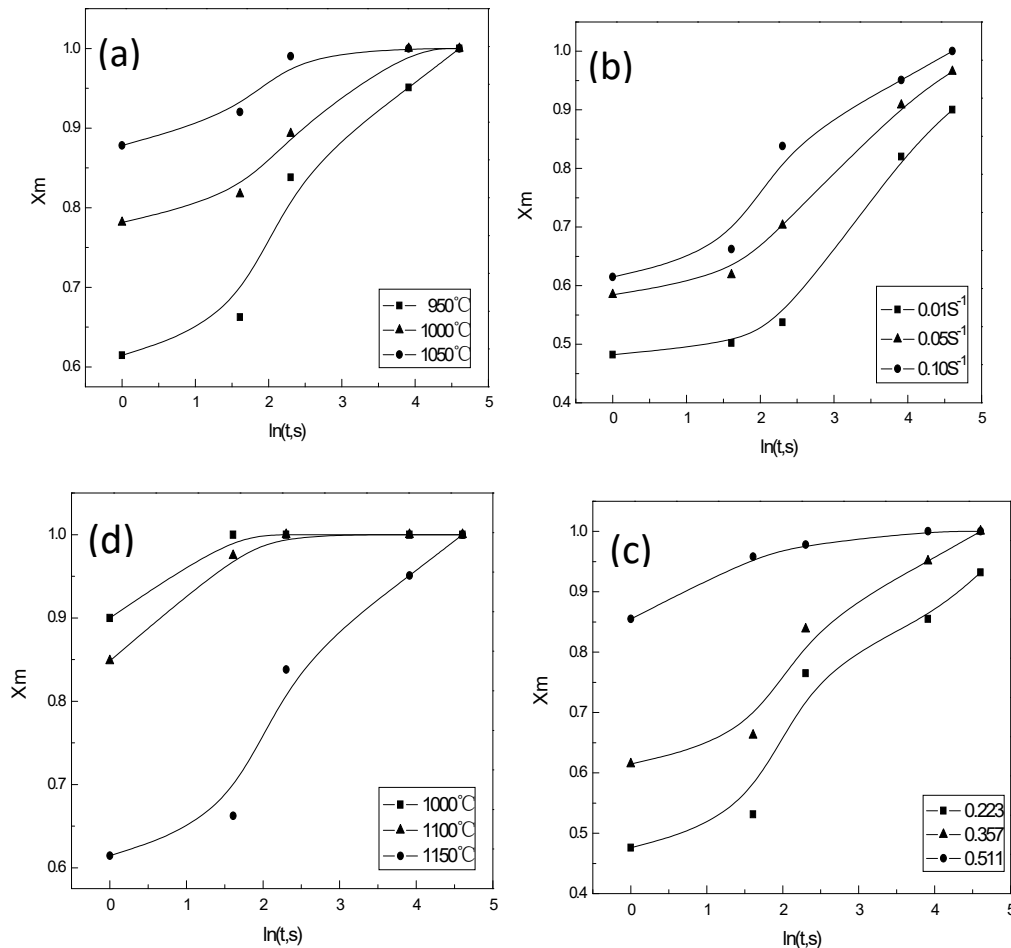
The load stroke data of the test was recorded, and the true stress-strain curves under various deformation conditions were plotted. The sub-dynamic recrystallization and static recrystallization softening fraction were determined by the 0.002 compensation method. The samples after the thermal simulation test were cut along the axial direction near the thermocouple joint, grinded and polished, and etched with a supersaturated picric acid detergent solution at 75-85°C for 60s, and the microstructures were observed by a LEICAQ 550 IW optical microscope. Ten different fields of view were randomly selected and measured 5 times respectively, and then the average value was taken as the average grain size value of austenite.

3. Experimental results and analysis

3.1. Sub-dynamic recrystallization

The effect of process parameters on the sub-dynamic recrystallization softening fraction of the invested steel is shown in Figure 1. It can be seen from Fig.1 (a) that the sub-dynamic recrystallization is very fast, whose fraction is as high as 0.62 at an interval of 1s at 950 °C, and when the pass time is 10s, the sub-dynamic recrystallization fraction is higher than 0.84. The sub-dynamic recrystallization softening fraction increases rapidly with the increase of deformation temperature, and it is due to the increase of recrystallization grain boundary mobility, which is beneficial to dynamic recrystallized grains growing up in the interval. The sub-dynamic recrystallization fraction also increases with the increase of strain rate shown in the Fig. 1(b). It is because that at the same deformation temperature, the greater the strain rate, the greater the work hardening, and the smaller the dynamic recovery and dynamic recrystallization, resulting in an increase of the dislocation density during thermal deformation, so that the driving force of sub-dynamic recrystallization is increased, and sub-dynamic recrystallization is more likely to occur. As shown in Fig. 1(c) that the sub-dynamic recrystallization fraction increases with the increase of the deformation amount under the same pass interval, but the degree of change is different. When the deformation is true strain 0.511 and the interval is 1s, the sub-dynamic recrystallization softening rate is as high as 0.85. This is because the tested steel has completely dynamic recrystallization under this pre-strain. Meanwhile, the sub-dynamic recrystallization softening rate did not change much as the deformation to 0.223 and 0.357 at the same interval. Under this pre-strain, the tested steel partially undergoes dynamic recrystallization, and so the fraction of sub-dynamic recrystallization also decreases. The tested steel was austenitized at 1000°C, 1100°C and 1150°C to obtain different initial austenite

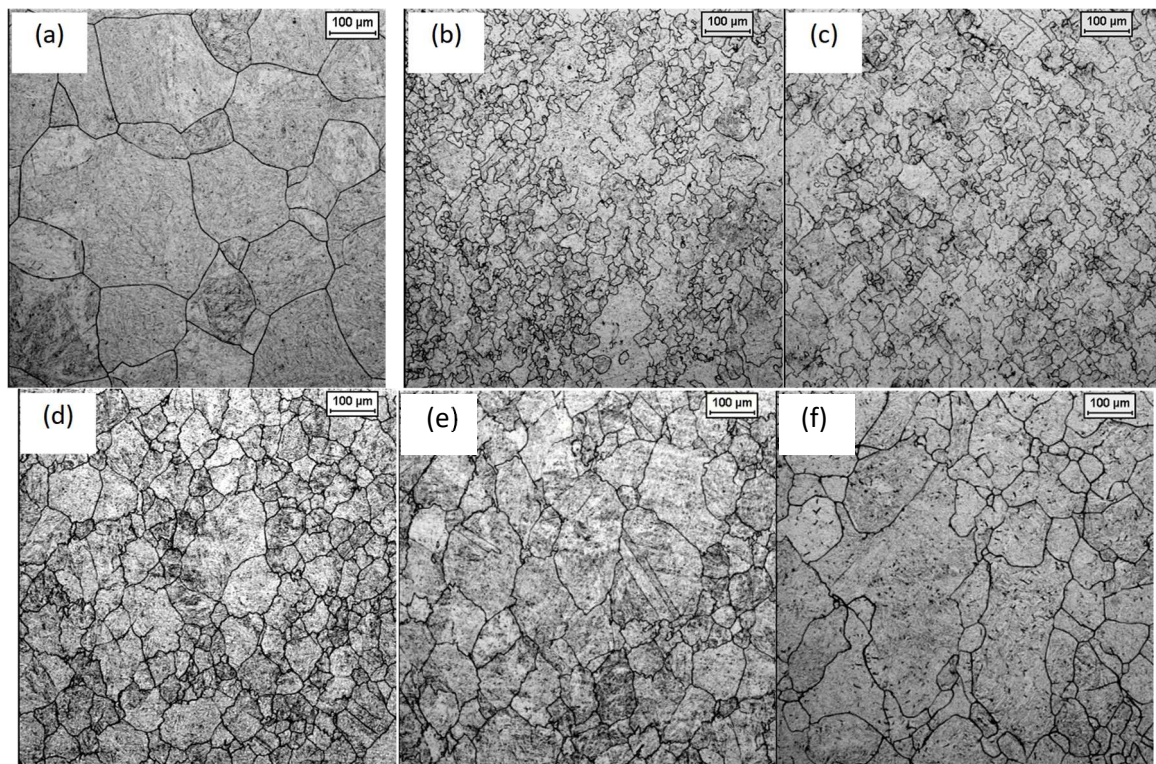
grain sizes (237.2 μm , 355.64 μm and 520.71 μm , respectively), the effect of initial austenite grain size on sub-dynamic recrystallization of GCr15 bearing steel is shown in Figure 1(d). It can be seen from the figure that the sub-dynamic recrystallization softening rate increase with the reduction of the initial grain size, but it is obscure as the austenitizing temperature below 1100°C.



(a) Deformation temperature, (b) strain rate, (c) deformation amount, (d) austenite grain size

Fig 1. Effects of parameters on sub-dynamic recrystallization softening fraction of GCr15 steel

Under the strain rate of 0.1 s⁻¹, deformation temperature of 950°C, and the first pass of 0.357, the microstructure at different intervals and the morphology of original austenite at 950 °C is shown in Fig.2. The austenite is equiaxed before the thermal deformation at 950°C, grain boundary is straight, and the average grain diameter is 207.5 μm , as shown in Fig. 2(a). The sample compressed after the first pass is immediately quenched and the microstructure is observed shown in Fig.2 (b), a small amount of flattened zone exists, and the dynamic recrystallization fraction is about 80%. The microstructure of quenched sample which held 1s after the first compressing is shown in Fig. 2 (c), there is no deformation zone, the grains are relatively uniform, the grain boundary is bent and the average grain size is 79.6 μm . When the interval is 5 to 100 s, the recrystallized grains gradually grow and the grain boundaries become round. The average recrystallized grain size is 125.6 μm at intervals of 5s, and it reaches 240.87 μm at 100 s. Sub-dynamic recrystallization is mainly the static growth of crystal nuclei formed during dynamic recrystallization, and its growth rate is very fast. The factors affecting dynamic recrystallization and static growth will all affect the sub-dynamic recrystallization.

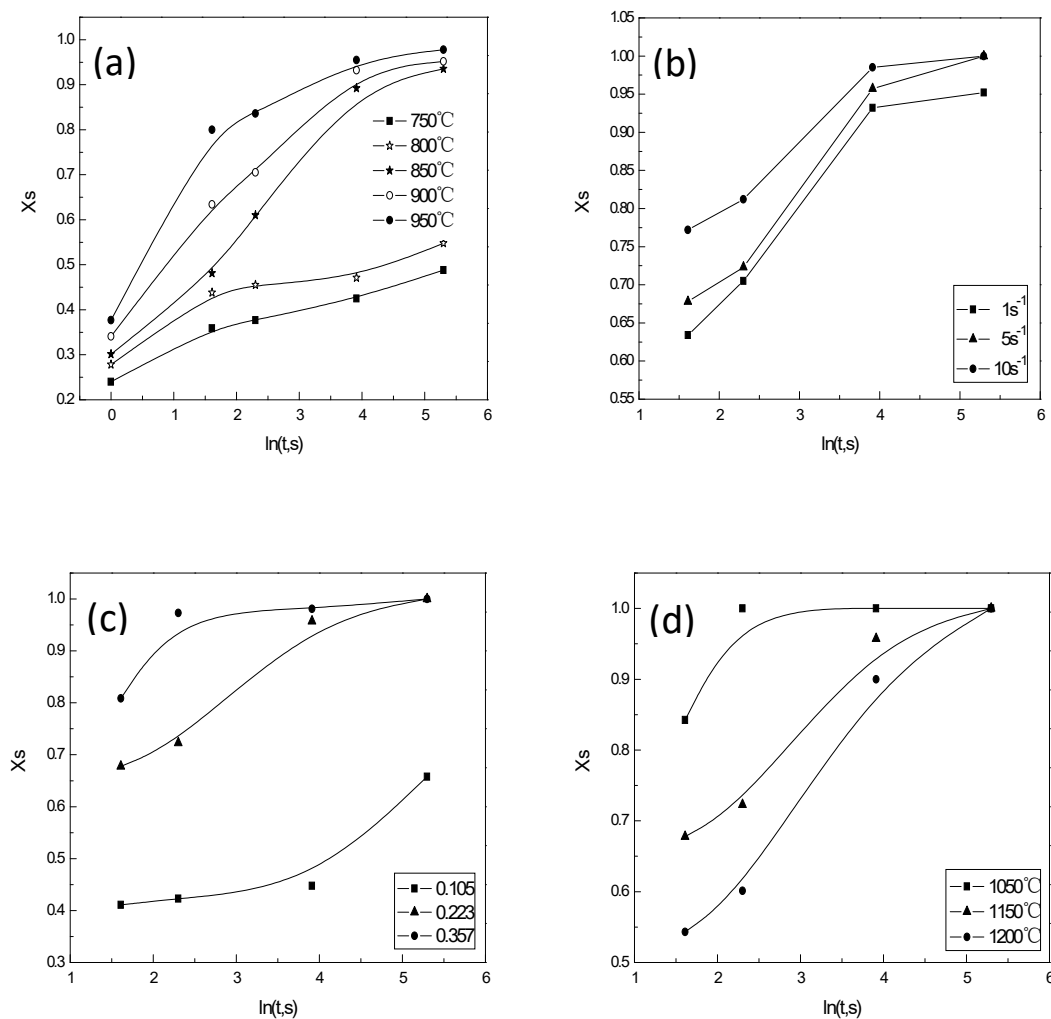


(a) Without deforming, (b) $t=0s$, (c) $t=1s$, (d) $t=5s$, (e) $t=50s$, (f) $t=100s$

Fig 2. Microstructures without deforming and sub-dynamic recrystallization morphology held different times after deforming at 950°C

3.2. Static recrystallization

The effect of process parameters on the static recrystallization softening rate of the tested steel is shown in Fig.3. It can be seen from Fig. 3(a) that the graph is divided into two regions by the two curves at 800°C and 850°C . When the deformation temperature is lower than 800°C , the static recrystallization rate is relatively slow, and when the temperature is higher than 850°C , the static recrystallization rate of the tested steel is faster. The static recrystallization softening fraction increases slowly with the increase of temperature deformed at $750\text{--}800^{\circ}\text{C}$. When the deformation temperature rises to 850°C , the static recrystallization fraction increases sharply, and then with the deformation temperature increases, it does not change much. This is because the higher the deformation temperature, the easier the recrystallization is, and the effect of recrystallization temperature on the recrystallization nucleation and growth rate is exponential, so static softening fraction generally increases with increasing temperature, but the increase is limited. The static softening fraction increases as the holding time increases in the same other conditions. However, the increase of static softening fraction is also slowly with the increase of the holding time, as the holding time reaches a certain value. When the deformation temperature is above 850°C and the holding time is less than 10 s, the static softening fraction increases rapidly with the increase of holding time, but it increases little with the increase of holding time which is longer than 10s . Therefore, the recrystallization rate can be controlled through controlling the interval between the passes reasonably in the rolling process and the steel products with excellent microstructure and mechanical properties can be obtained.



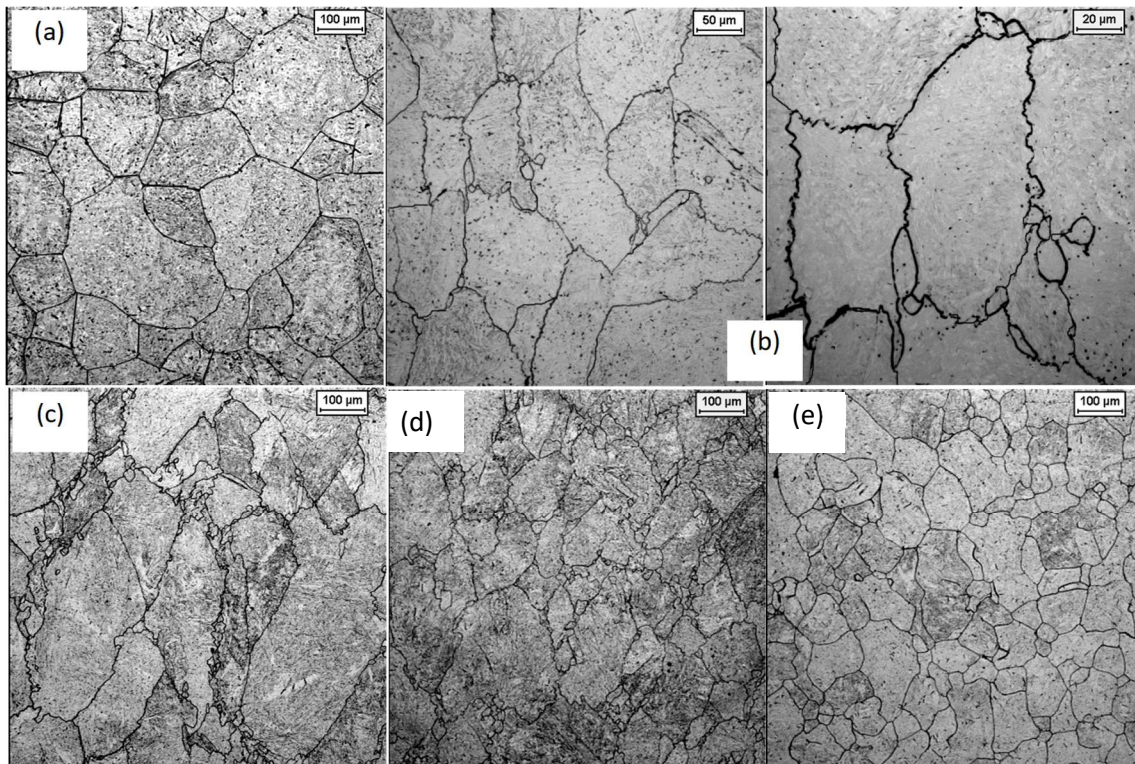
(a) Deformation temperature, (b) strain rate, (c) deformation amount, (d) austenite grain size

Fig 3. Effects of parameters on static recrystallization softening fraction of GCr15 steel

What can be seen from Fig. 3(b) is that the static recrystallization rate increases with the increase of strain rate. This is because the higher the strain rates, on the one hand, the faster the rate of dislocation density proliferation, on the other hand, the lower dynamic recovery, and the slower the rate of dislocation disappearance, so dislocation density is higher inside the material after thermal compression. The high dislocation density results in an increase of driving force for static recrystallization, and thus the rate of static recrystallization is also faster.

As shown in Fig.3(c), as the amount of deformation increases, the rate of static recrystallization increases because the work hardening plays a dominant role in the deformation process before the strain reaches dynamic recrystallization, and thus, with the increase of deformation amount, the dislocation density of the material increases rapidly, and the driving force for static recrystallization increases.

The tested steel was austenitized at 1050°C, 1150°C and 1200°C to obtain different initial austenite grain sizes (292.68 μm , 520.71 μm and 532.44 μm , respectively), the effect of initial austenite grain size on static recrystallization of GCr15 bearing steel is shown in Fig. 3(d). It can be seen from the figure that the smaller the initial grain size, the greater the static recrystallization softening rate.



(a) Without deforming, (b) $t=0s$, (c) $t=1s$, (d) $t=10s$, (e) $t=200s$

Fig 4. Microstructures without deforming and static recrystallization morphology held different times after deforming at 900°C

Microstructure of quenched sample held at different intervals after compressing under the conditions of strain rate for 5s-1, deformation temperature for 900°C , and first pass for 0.223, and the original grain morphology of austenite at 900°C is shown in Fig.4. The austenite is substantially equiaxed before thermal deformation at 900°C , the grain boundary is straight, and the average grain diameter is $176.7\text{ }\mu\text{m}$, as shown in Fig.4 (a).

Sample compressed by the first pass is quenched immediately, observing the microstructure, as shown in Fig.4 (b), a small amount of recrystallized nucleus appeared on the flattened elongated deformation zone, and the grain boundary was jagged, which created conditions for the formation of the static recrystallization.

The microstructure of sample held for 1 to 10s after first pass compression is shown in Fig.4 (c~d). The number of recrystallized nuclei at the grain boundary gradually increases, and the deformation zone gradually decreases. Holding for 10~200s, the recrystallized grains gradually grow, the length of the deformation zone decreases, and the grain boundary becomes round. The average length of the deformation zone is $216.93\text{ }\mu\text{m}$ at intervals of 10s, and the average length of the deformation zone drops to $149.53\text{ }\mu\text{m}$ at intervals of 200s.

4. Discussion

The process of static recrystallization includes nucleation and growth, and its velocity is lower than the sub-dynamic recrystallization rate. The higher the deformation temperature, the higher the strain rate, and the larger the deformation amount, and the smaller the original austenite grain size, static recrystallization is more likely to occur after thermal deformation. In the production process of the wire bobs, due to the rapid rolling speed, and the gap time of the rolling pass is very short (less than 1 s).

Static recrystallization is difficult to occur. However, the static recovery and static recrystallization can occur in the spinning process after the final rolling. Therefore, increasing the reduction of final rolling appropriately and increasing the spinning temperature will facilitate static recovery and static recrystallization, which will reduce austenite distortion and make the structure more uniform.

5. Conclusion

(1) The higher the deformation temperature and the strain rate, the larger the deformation amount, and the smaller the original austenite grain size, the more likely the sub-dynamic recrystallization and static recrystallization after thermal deformation of GCr15 bearing steel.

(2) Increasing the deformation amount of final rolling and the spinning temperature appropriately will facilitate static recovery and static recrystallization.

Acknowledgments

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