Hot Deformation Behavior and Processing Map of 5356 Aluminum Alloy

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Abstract. The hot compression deformation of 5356 aluminum alloy was performed with the deformation temperature 300~500℃ and the strain rate 0.01~10s⁻¹ by using Gleeble-3500 thermal mechanical simulator. The microstructure of the alloy was analyzed by ZEISS metallographic microscope. The results show that the flow stress of 5356 aluminum alloy decreases with the increase of deformation temperature and increases with the increase of strain rate. 5356 aluminum alloy is mainly dynamic recovery under low strain rate conditions, such as 0.01 S⁻¹, 0.1 S⁻¹. The alloy is discontinuous dynamic recrystallization under high strain rate conditions, such as 1 S⁻¹, 10 S⁻¹. The hot processing map of 5356 aluminum alloy was established with the strain of 0.2~0.5, can provide an effective data reference for the development of high-end 5356 aluminum alloy wire continuous rolling process.

1. Introduction

5356 aluminum alloy belongs to the 5 series of aluminum -magnesium alloy. Due to its good plasticity, fracture toughness, corrosion resistance, plastic working performance and weldability, and its good compatibility with most aluminum-based alloys, it is widely used as the welding material for MIG welding of transportation vehicle body [1], so as to realize lightweight transportation. At present, the production technology of 5356 aluminum alloy welding wire is mainly owned by famous international welding wire manufacturers, such as VAW of Germany, Alcoa of the United States, Kok of Japan, Saf of France, Gimax of Italy, Indalco of Canada, etc. In particular, the continuous casting and rolling production technology of 5356 aluminum alloy welding rod is strictly confidential, which leads to the high-end 5356 aluminum alloy used for welding aluminum alloy car body of rail transit such as high-speed railway in China More than 90% of welding wire is imported [2-4].

The chemical composition of Mg in 5356 aluminum alloy is 4.5~5.5%, which is a kind of high magnesium mechanical aluminum alloy (magnesium content is more than 3%). Compared with the current domestic electrical alloy, the strength, plasticity and deformation of 5356 aluminum alloy under high temperature are lack of research. Flow stress and deformation characteristics are the basic parameters of material forming in the process of hot deformation. In this paper, hot compression deformation at high temperature and isotherm experiment of 5356 aluminum alloy was carried out by Gleeble-3500 thermal simulation machine, and the change law of microstructure under high temperature deformation condition was analyzed. The true stress-strain curves of 5356 aluminum alloy under different strain rates and deformation temperatures were obtained. Based on the hot working diagram of 5356 aluminum alloy, the instability zone of 5356 aluminum alloy hot working process is analyzed, hoping to provide data guidance for the localization of aluminum alloy welding wire continuous casting and rolling technology production of 5356 aluminum alloy.
2. Experimental Methods
The single pass hot compression deformation test of 5356 aluminum alloy was carried out on Gleeb-3500 thermal simulation machine with 50% compression deformation. The deformation temperature was 300, 350, 400, 450, 500°C, and the strain rate was 0.01, 0.1, 1, 10 S⁻¹. Before hot compression, the graphite flakes are pasted with lubricant at both ends of the sample and the indenter to reduce the friction force during the hot compression process and improve the deformation uniformity. The samples were heated by vacuum resistance at a heating rate of 5°C/ s. The samples were heated to the set temperature and kept for 2 minutes. After the hot compression deformation, the samples were cooled rapidly by water quenching. The experimental data were collected automatically by computer, and then the true stress-strain curve of 5356 aluminum alloy was drawn by origin. The metallographic samples were prepared by coating the anode with WYJ-0~30 V/5 A DC regulated power supply, and observed by Zeiss metallographic microscope with polarizing light.

3. Experimental Results and Analysis
3.1. Stress Strain Curve Of 5356 Aluminum Alloy
Figure 1 shows the true stress-strain curve of 5356 aluminum alloy under different deformation conditions. It can be seen from Figure 1 that the flow stress increases rapidly with the increase of deformation degree at the beginning of hot compression deformation of 5356 aluminum alloy, showing work hardening. When the deformation degree increases to a certain extent, the deformation is stable at the beginning, and the change trend of flow stress is gradually gentle, and the work hardening and dynamic softening mechanism are in phase Balance.

It can be seen that deformation temperature and strain rate seriously affect the high-temperature flow stress of 5356 aluminum alloy. At the same deformation temperature, the flow stress increases with the increase of strain rate, and 5356 aluminum alloy has positive strain rate sensitivity. Under the same strain rate condition, the flow stress decreases with the increase of deformation temperature, and 5356 aluminum alloy shows negative temperature sensitivity. The peak flow stress of 5356 aluminum alloy is about 4 times higher than that of pure aluminum, and the difference is large [5]. For example, under the condition of pure aluminum 300°C, $\dot{\varepsilon} = 1.0$ S⁻¹, the value of flow stress for pure aluminum is 50 MPa, For 5356 aluminum alloy, 187 MPa is required, which puts forward higher requirements for mechanical alloy equipment and technology. Considering equipment performance and deformation process comprehensively, higher deformation temperature and lower deformation rate should be adopted for 5356 aluminum alloy hot working to ensure smooth production.

![Figure 1. The true stress-strain curve of 5356 aluminum alloy at different deformation condition](image-url)
3.2. Establish Hot Processing Map Of 5356 Aluminum Alloy

The process of establishing the hot working diagram of 5356 aluminum alloy when the ε is 0.2, 0.3, 0.4, 0.5 is as follows. The logarithm of true stress value σ under low strain rate condition (ε = 0.01, 0.1, 1s⁻¹) and high strain rate condition (ε = 10 s⁻¹) is logarithm, then lσ-lgε is fitted by cubic spline interpolation. The expression after fitting is shown in equation (1).

\[ \lg \sigma = a + b(lg \epsilon) + c(lg \epsilon)^2 + d(lg \epsilon)^3 \]  

Where a is the intercept of cubic spline curve on Y axis after fitting; b, c and d are coefficients of cubic spline curve. Equation (2) is derived from both ends of equation (1). Where m is the strain rate sensitive index factor, the values of m can be obtained by introducing the values of b, c, d and lgε into equation (2).

\[ \frac{\partial \lg \sigma}{\partial \lg \epsilon} = b + 2c(lg \epsilon) + 3d(lg \epsilon)^2 = m \]  

In the dynamic material model, the dissipation efficiency factor η is a dimensionless parameter, which describes the relationship between the ratio of energy consumed by microstructure evolution and the total energy consumed in the process of thermal deformation. The relationship between η and strain rate sensitive index factor m is shown in equation (3). The value of η can be obtained by introducing m into equation (3). The contour map drawn in the T-lgε plane is the power dissipation diagram. The larger the dissipation rate factor η, the better the machinability of the material in this area [6-10].

\[ \eta = \frac{2m}{m+1} \]  

In the process of hot deformation, the rheological instability criterion of materials is shown in equation (4), where ζ (ε) is the instability parameter.

\[ \zeta(\epsilon) = \frac{\partial \ln[m/(m+1)]}{\partial \ln \epsilon} + m < 0 \]  

Put the values of m and lgε into equation (4) to obtain the value of ζ (ε). Draw the area of ζ (ε) <0 in the T-lgε plane to obtain the instability diagram. The power dissipation diagram and the instability diagram can be superimposed to obtain the 5356 aluminum alloy hot processing map as shown in figure 2.

**Figure 2.** The hot processing map of 5356 aluminum alloy (a) ε=0.2, (b) ε=0.3, (c) ε=0.4, (d) ε=0.5
Due to the high strength of 5356 aluminum alloy wire rod in hot continuous rolling process, the single pass deformation is not more than 35%. Therefore, this paper mainly analyzes the hot working diagram of 5356 aluminum alloy when the true strain is 0.4 (figure 2c). It can be seen that there are two unstable regions which represented by the shadow part in the hot working diagram of 5356 aluminum alloy when the true strain is 0.4. Instability zone I: temperature 300 ~ 330℃, strain rate 0.01 ~ 0.4 S⁻¹; instability zone II: temperature 320 ~ 440℃, strain rate 0.04 ~ 10 S⁻¹.

Generally speaking, material instability is due to adiabatic shear bands or local rheological instability or cracks in the process of deformation[11]. As shown in figure 3a, under the deformation conditions of T= 300℃ and 0.01s⁻¹, the local rheological instability phenomenon occurs in the microstructure of 5356 aluminum alloy; as shown in figure 3b, cracks appear in the alloy structure under the deformation conditions of T= 400℃ and 1.0S⁻¹. The unstable process zone is not suitable for machining and should be avoided in the actual processing. As shown in figure 3c, figure 3d, under the deformation conditions of T= 450℃ and 0.1S⁻¹, T= 450℃ and 10S⁻¹, no deformation instability of 5356 aluminum alloy during hot compression deformation.

![Figure 3. Thermal compression Metallographic microstructure of 5356 aluminum alloy](image)

4. Conclusion
(1) The flow stress of 5356 aluminum alloy decreases with the increase of temperature and increases with the increase of strain rate;

(2) When the strain rate is low, the dynamic recovery of the alloy structure occurs, and when the strain rate is high, the dynamic recrystallization occurs;

(3) When the true strain of 5356 aluminum alloy is 0.4, there are two instability regions in the hot working diagram. The first zone is temperature 300 ~ 330℃, strain rate is 0.01 ~ 0.4 S⁻¹; the second
zone is temperature 320 ~ 440°C, strain rate is 0.04 ~ 10 S⁻¹, which should be avoided in the process of processing.

5. Acknowledgments
The project was financially supported by Science and Technology Research program of Chongqing municipal education commission (KJZD-M201801401) and Talent start found of Changjiang Normal University(2018KYQD006)

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