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Mechanical behavior of LC_4 alloy in semisolid state at high volume fractions of solid①

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[Abstract] The mechanical behavior of LC_4 alloy in the semisolid state at high volume fractions of solid has been studied through unconstrictive compressing test. The results show that peak stress mainly depends on grain boundary's cohesion and instantaneous strain rate sensitivity in the semisolid state, which is similar to that in the solid state. Analyses on microstructures and status of compressive stress of specimen demonstrate that segregation of liquid-solid phase is mainly affected by strain rate and deformation temperature. There are mainly two kinds of flow in liquid phase: either from the region with relatively large hydrostatic compressive stress to the region with relatively small hydrostatic compressive stress or from the grain boundaries perpendicular to the compression axis to the grain boundaries with a certain directional angle to the compression direction. Based on the above results, compressive deformation mechanism mainly depends on deformation temperature, strain rate and stress state.

[Key words] LC_4 alloy; semisolid; mechanical behavior; segregation of liquid-solid phase
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1 INTORDUCTION

Alloys with equiaxed microstructure exhibit significantly lower flow resistance in the semisolid state than alloys with dendritic microstructure. Their dual (thixotropic) behavior (solid-like in the unperturbed state and liquid-like during shearing) has been the basis for semisolid processing. So semisolid metalworking has combined merits of casting and forging process. Complicated parts not only can be formed by smaller force with one working, but also has a higher accuracy of sizes and synthetic mechanical properties. The process is considered the most prospective near-net shape forming process in the 21st century[1~7]. Consequently, it is necessary to carry out pertinent theoretical and experimental researches.

Because mechanical behavior of semisolid alloys is completely different from that of solid alloys due to its peculiar properties[8~10], it is necessary to carry out study on the mechanical behavior so as to lay a theoretical basis for the semisolid metalworking. The aims of unconstrictive compressing test for LC_4 alloy at high solid fractions in this paper are: firstly to identify the salient features of the mechanical behavior and strain rate sensitivity of semisolid alloys; and secondly to evaluate the effect of macroscopic variables such as deformation velocity, deformation temperature on the mechanical response of the alloy and the final microstructure such as segregation of liquid phase and deformation of solid phase. In addition, the flow behavior of semisolid alloys with equiaxed microstructure at high solid fractions is also described.

2 EXPERIMENTAL

LC_4 alloy was employed as experimental materials, which was mainly composed of Al, Zn and Mg. The melting of the alloy starts at 586 ℃ and ends at 626.6 ℃. The compression test was conducted on INSTRON 1186 universal testing machine. The initial compression specimen is 15 mm in diameter and 23 mm in height. The deformation temperatures selected were 595 ℃ and 605 ℃, with the corresponding solid fraction being 85% and 74%, respectively. The specimens were maintained at these two temperatures in furnace for about 10 min before the compression began and the temperature fluctuation was controlled in the range of ±2 ℃. Strain rates of compressive deformation were 0.004, 0.016 and 0.04 s^{-1}, respectively. Strain rate jump test was performed at 595 ℃. Graphite powder was sprayed on two ends of the specimens to reduce friction. Finally, the compression specimens of different tests were prepared for microstructure observations.

3 RESULTS AND ANALYSES

3.1 Compressive deformation

Compressive curves of true stress vs true strain at various deformation temperatures and strain rates are shown in Figs. 1 and 2. The curves have similar shapes at 595 ℃ and 605 ℃. The flow stress decreas-

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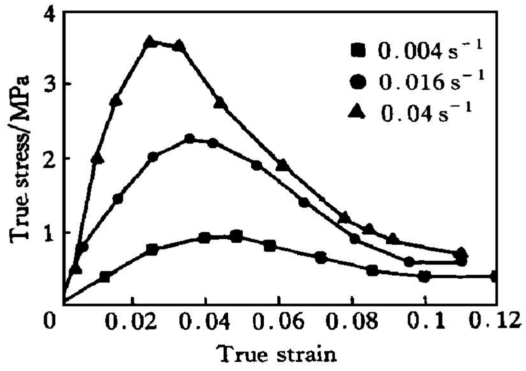

Fig. 1 Compressive true stress-true strain curves at 595 ℃

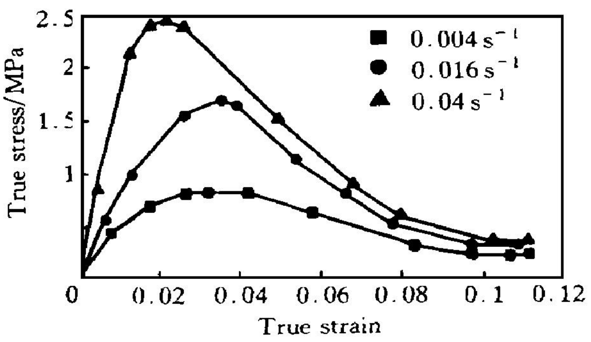

Fig. 2 Compressive true stress-true curves at 605 ℃

es with increasing deformation temperature and decreasing strain rate, and in high strain rate, the peak stress occurs at lower true strain. The peak stress observed experimentally depends on both cohesion of solid grains and internal friction of the alloy. The cohesion at the grain level reflects the strength of unwetted grain boundaries. The internal friction is referred to the shear resistance in the fully cohesionless state in the material, and the shear resistance comes from the relative motion of grains. Typical stress ratio of the peak-to-plateau for cohesionless soils is 2[11]. It can be seen from Figs. 1 and 2 that the peak-to-plateau stress ratios of all curves in this work are larger than 2, and the higher values observed here suggest that the peak stress mainly depends on the cohesion of grain boundaries. After peak stress, cracks begin to appear and strain softening dominates over the whole process, which make the overall strength of material decrease. In the end, the overall strength of material decreases to a plateau, stress almost does not change with increasing strain. It is obvious that strain softening increases with increasing deformation temperature for compression specimen at semisolid state. On the contrary, strain softening depends on dynamic recovery and dynamic recrystallization of deformation process at solid state[12].

Fig. 3 shows true stress vs true strain curve of jumping strain rate at 595 ℃. It can be seen from the

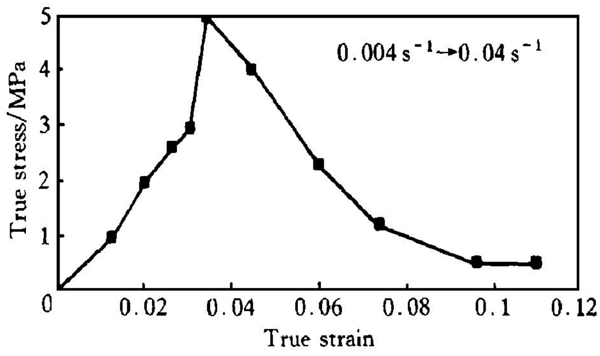

Fig. 3 True stress-true strain curve at jumping strain rate

figure that the true stress changes abruptly from 2.8 MPa to 4.9 MPa due to that strain rate jumps from 0.004 s^{-1} to 0.04 s^{-1} when true strain reaches 0.03.

As noted above, compressive flow stress of LC_4 alloy is not only a function of deformation temperature but also a function of strain rate. The alloy possesses strain rate sensitivity in semisolid state, which means that deformation temperature and strain rate are two key factors to determine the main deformation style of compressive deformation in semisolid state.

3.2 Effects of upsetting on microstructures

Fig. 4 shows cross-sectional microphotographs before and after upsetting. Figs. 4(a) and (b) represent the microstructures of upsetting at 595 ℃ and 605 ℃, respectively, under the strain rate of 0.04 s^{-1}. It is obvious that the higher the deformation temperature, the more serious the segregation of liquid-solid phase, and accordingly it is easy to incur the cracks to form along compression axis. Figs. 4(b), (c) and (d) show the microstructures using deformation temperature of 605 ℃ and strain rates of 0.04, 0.016 and 0.004 s^{-1}, respectively.

It can be concluded that the lower the strain rate, the more serious the segregation of liquid-solid phase and the more sensitive to produce cracks along compression axis; on the contrary, the higher the strain rate, the more uniform distributing the solid phase.

3.3 Stress distribution state of compression specimen

Schematic diagram of upsetting behavior is shown in Fig. 5. The stress distribution in the compression specimens between two plane plates is very complicated because of the influence of the friction on two ends of the cylinder. In the regions near the interfaces between the punch and the specimen, the hydrostatic compressive stress is relatively large, while it decreases in the increasing direction of the radius.

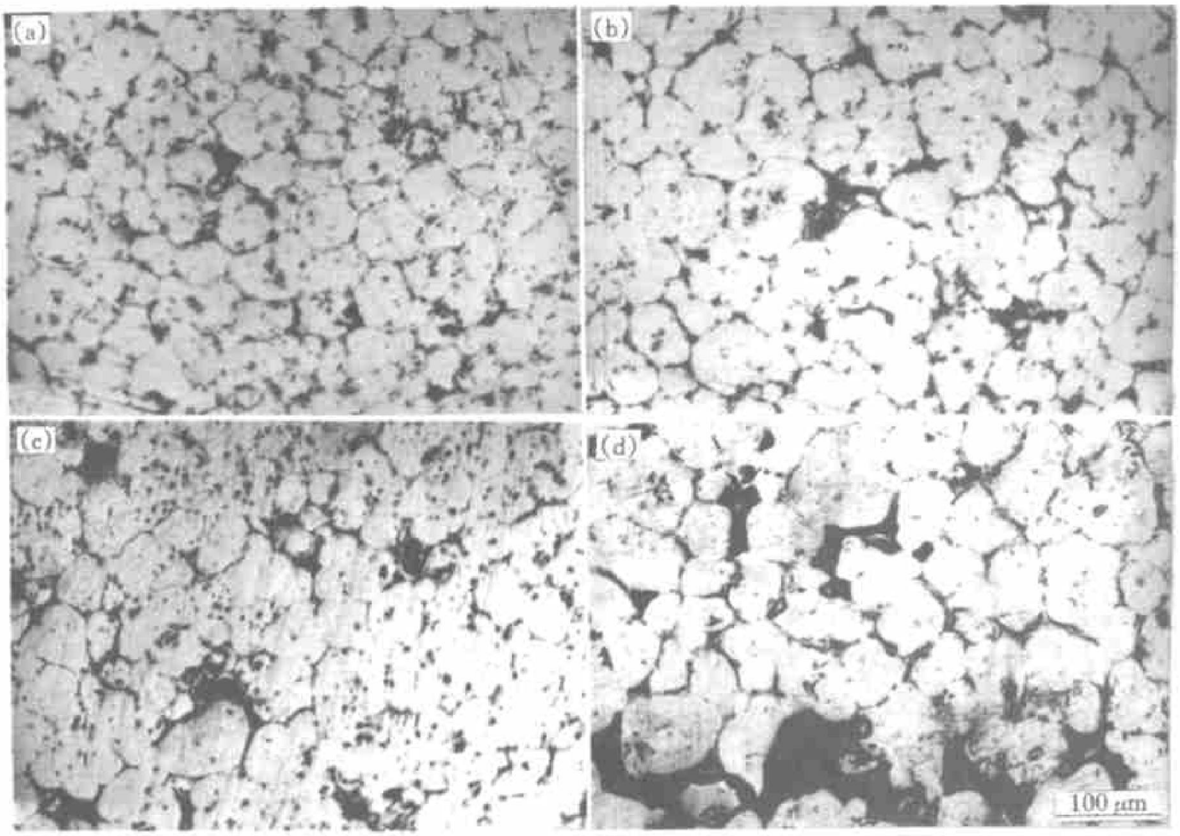

Fig. 4 Microstructure of semisolid alloy after upsetting for various deformation temperatures and strain rates

(a) —0.04 s^{-1}, 595 ℃; (b) —0.04 s^{-1}, 605 ℃; (c) —0.016 s^{-1}, 605 ℃; (d) —0.004 s^{-1}, 605 ℃

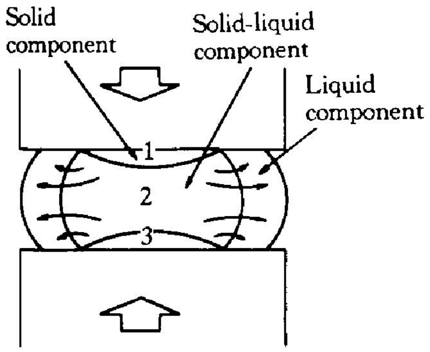

Fig. 5 Schematic diagram of upsetting behavior

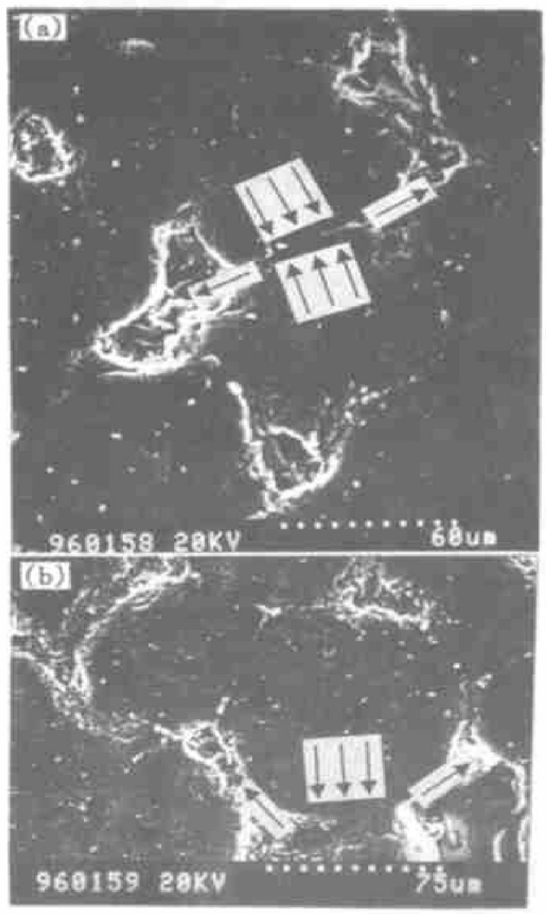

Fig. 6 Microstructure at different position of compressive specimen

In the peripheral region of the compressive specimen, the hydrostatic compressive stress in the liquid phase is relatively small and there is a tensile stress in tangential direction. The compressed specimen was cut at the central plane along the compression direction to observe macrostructure. It can be seen that the cavities are almost distributed in region 2 (magnified photographs of various vertical section are shown in Fig. 6), but regions 1 and 3 are nearly free of cavities. The liquid phase in regions 1 and 3 flows into the regions with a relatively small hydrostatic compressive stress through the existing channels under a relatively high hydrostatic compressive stress because the hydrostatic compressive stress in regions 1 and 3 is relatively large at the initial deformation stage. On the other hand, the liquid phase will move from central regions to outside regions through the channels existing in the specimen, because the hydrostatic compressive stress in the central regions is high, but the hydrostatic compressive stress in the outside regions is low, which is the redistribution of liquid phase on the macro scale. Otherwise, liquid phase may also shift due to different forced states in continuous grain boundaries or the changing of volume resulting from deformation, which can be seen from Fig. 6. It is possible for the liquid phase to flow to the region with tensile stress (see Fig. 6(a)) under the condition of normal compressive stress or to flow from the grain boundaries perpendicular to the compression axis to the grain boundaries with a certain directional angle to the compression direction (see Fig. 6(b)).

4 CONCLUSIONS

1) Abrupt change of strain rate may lead to abrupt change of stress at the same deformation temperature, which explains that LC_4 alloy is strain rate sensitivity.

2) The higher the strain rate, the more uniformity the microstructure, otherwise, the lower the strain rate, the more serious the segregation of solid-liquid phase.

3) The stress ratios of peak to plateau of compressive true stress-true strain curves for LC_4 alloy in semisolid state are larger than 2, which makes clear that peak stress mainly depends on grain boundary's cohesion.

4) Liquid phase may flow from the regions with relatively large hydrostatic compressive stress to the regions with relatively small hydrostatic compressive stress, or flow from the grain boundaries perpendicular to the compression axis to the grain boundaries with a certain directional angle to the compression direction.

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