Formation of nanocrystalline during flash welding of 0Cr16Ni22Mo2Ti steel

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Abstract A nanocrystalline layer was fabricated in bond area of 0Cr16Ni22Mo2Ti austenite steel using flash welding. The mean grain size near bond line is about 20 nm, and the farther the distance from bond line, the larger the size of the nanocrystalline. The thickness of the nanocrystalline layer is about 50 μm. The formation mechanism of the nanocrystalline may be that the metal in semisolid state is deformed severely and its solid grains are fragmented.

Keywords: nanocrystalline materials, flash welding, plastic deformation.

Materials with ultrafine grain (UFG) structures and grain size in the range of nanometers or submicrometers have attracted considerable attention of researchers in various areas. Usually, the mechanical alloying, ultrafine powder sintering and amorphous cystallining methods are used to prepare block nano-materials. Fast heating can refine the austenite grains. Recent investigations have demonstrated that materials with UFG structure (nano- and submicron crystalline) can be produced by severe plastic deformation[1]. The nanomaterials can also be obtained through supercooling treatment[2]. However, there are no reports on the question of whether the nanocrystalline structure can be obtained or not by severe deformation of steel in the semisolid state. High-speed rail demands the welding of ZGMn13 steel crossing with carbon steel rail. Many materials, including 1Cr16ni22Mo2Ti steel, were chosen as welding materials and the flash welding technology was employed for experiment[3]. In studying the microstructures of the bond area, we found that the microstructure of 0Cr16Ni22Mo2Ti steel near the bond line was the nanocrystalline. This note studies the nanocrystalline structure and discusses its formation mechanism.

1 Materials and methods

The experimental materials were 0Cr16Ni22Mo2Ti austenite stainless steel and ZGMn13 austenite steel. The 0Cr16Ni22Mo2Ti steel was smelted in a vacuum induction furnace, and then forged and cooled in air. A GAAS80/700 model flash welder made in Sweden was used to weld the 0Cr16Ni22Mo2Ti steel and ZGMn13 steel. During the flash welding the welding materials were heated to melt state quickly and then welded together by severe plastic deformation. The welding thermal/ mechanical conditions are as follows: heating speed, 30℃/s; heating temperature, about 1 400℃; deformation rate, 100 mm/s; deformation pressure, 70 MPa; cooling rate around melt point temperature, 30℃/s. A Formarst-F model dilatometer was used to study the phase transformation procedure of the 0Cr16Ni22Mo2Ti steel and ZGMn13 steel in the heat cycle of the flash welding. At the same time, their melting points were determined. Structural investigations of the welding joint were performed on an EM420 transmission electron microscope operating at 175 kV acceleration voltage and using selected area diffraction patterns, bright field and dark field images.

2 Results and discussion

The microstructures of the 0Cr16Ni22Mo2Ti steel forged are of recrystallized equiaxial grains, and its grain size is about 60 μm. The results of thermal expansion analysis indicate that the microstructure of 0Cr16Ni22-Mo2Ti steel and ZGMn13 steel are always of single austenite in the heating cycle of the flash welding. The melting points of the 0Cr16Ni22Mo2Ti and ZGMn13 are 1 285℃ and 1 370℃, respectively.

A typical microstructure of 0Cr16Ni22Mo2Ti steel in the bond area is shown in fig. 1. It is found that the microstructure of 0Cr16Ni22Mo2Ti steel is of nanocrystalline with f.c.c. structure, its average size near the bond line is about 20 nm. Using transmission energy spectrum analysis, we found that in the nanocrystalline the contents of alloying elements are Cr 16.8, Ni 21.2, Mo 2.3, Ti 0.51, which correspond to the average chemical composition of the 0Cr16Ni22Mo2Ti steel. In the bond area, the thickness of the nanocrystalline structure zone along the bond line is about 50 μm. The farther the distance from weld junction, the larger the nanocrystalline size, as shown in fig. 2. The structure in the heat affected zone (HAZ) is of austenite with a large amount of dislocation. However, the microstructure of ZGMn13 steel in the bond area is of usual austenite and there exists no nanocrystalline.

The formation mechanism of the nanocrystalline of 0Cr16Ni22Mo2Ti steel in the bond area may be that, in the process of the flash welding, the bond area in the semisolid state is deformed severely, the solid grains are fragmented. It is the same as the fact that the metals are fragmented by severe plastic deformation at room temperature[4]. In addition, compared with the microstr ucture of ZGMn13 steel in the bond area subjected to the same thermal/mechanical process it is indicated that the formation of the nanocrystalline in the 0Cr16Ni22Mo2Ti steel is connected with its chemical composition and melting point. Because the melting point of the 0Cr16Ni22Mo2Ti steel is low, its bond area was severely deformed in the process of the flash welding. The solid grains can be fragmented fully. In addition, the 0Cr16Ni22Mo2Ti steel contains Ti that can form TiN and hence effectively retard crystal growing. As in the area farther from the bond line the deformation of the steel is smaller and the fragment degree of the solid grains is lower, the nanocrystalline structure becomes irregular and its size becomes larger. Gradually it becomes usual austenite in structure, as shown in fig. 2. Fig. 3 shows the grain size distributions of the nanocrystalline of 0Cr16Ni22Mo2Ti steel.

Fig. 2 also indicates that the formation of the nanocrystalline is not caused by fast solidification. In the welding joint the temperature of the bond line is high, and its solidification rate is low. If fast solidification is the reason of the formation of the nanocrystalline, the size of nanocrystalline in the bond line should be the largest, and the size of grains far from bond line should be smaller. The result is to the contrary. In fact, after the flash welding the cooling rate of the bond line is low (only about 30 ℃/s around melt point temperature), which does not meet the condition of the fast solidification.

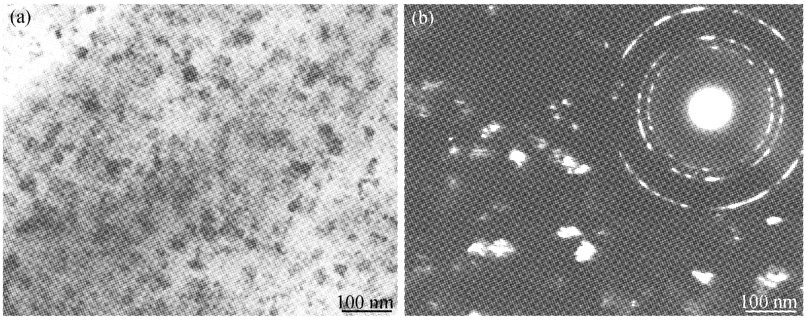

Fig. 1. Light-field TEM image (a) and dark-field TEM image (b) near the bond line of the 0Cr16Ni22Mo2Ti steel. The selected area is an electron diffraction pattern, showing that the microstructure is ultrafine crystalline with f.c.c. structure.

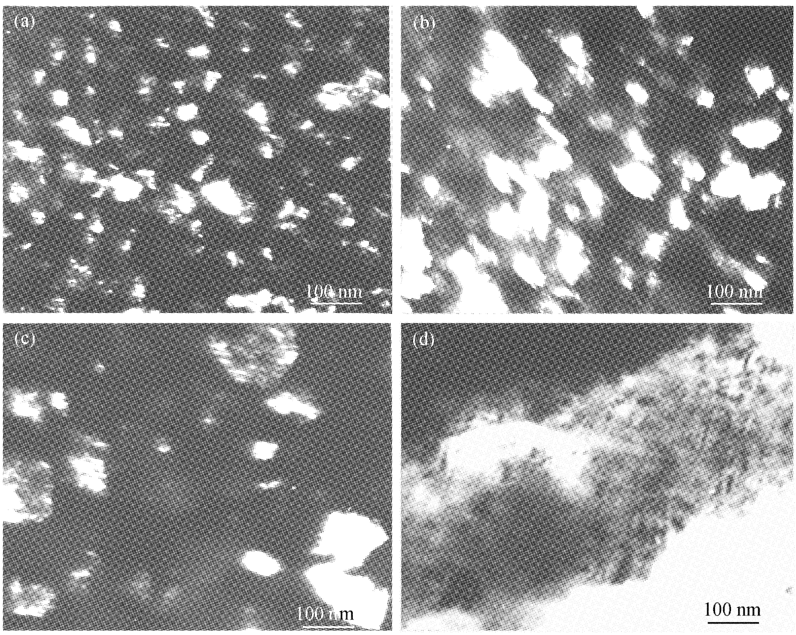

Fig. 2. The microstructures of the bond area of 0Cr16Ni22Mo2Ti steel at the distances of 2 (a), 10 (b), 30 (c) and 50 μm (d) from the bond line, respectively.

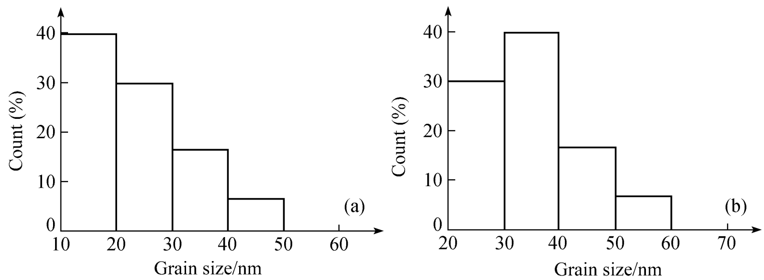

Fig. 3. Grain size distributions of the nanocrystalline of 0Cr16Ni22Mo2Ti steel, with (a) corresponding to fig. 1 and (b) corresponding to fig. 2(a).

A nanocrystalline layer with f.c.c. structure was fabricated in bond area of 0Cr16Ni22Mo2Ti austenite steel using flash welding. The formation mechanism of the nanocrystalline may be that the metal in semisolid state is deformed severely and its solid grains are fragmented.

In terms of mechanical behavior, steels with the nanocrystalline structures exhibit ultrahigh strength and superplastic-like behavior[5], they can be used to make very important parts. Based on defining the formation mechanism of the nanocrystalline of 0Cr16Ni22Mo2Ti steel, the precision parts whose microstructure is ultrafine crystalline can be made by using the method of subjecting the metal in semisolid state to pressure work.

References

1. Valiev, R. Z., Korznikov, A. V., Mulyukov, R. R., Structure and properties of ultrafine-grained materials produced by severe plastic deformation, Materials Science and Engineering, 1993, A168: 141.
2. Zhang Zhengzhong, Song Guangsheng, Yang Gencang, The microstructure characteristics of high undercooled bulk nanocrystalline Fe-B-Si eutectic alloy, Acta Metallurgica Sinica (in Chinese), 1999, 35(7): 693.
3. Zhang Fucheng, Xu Anyou, Wang Tiansheng, Study of weldability of ZGMn13 and U71Mn steels with help of gradient coating, Chinese Journal of Mechanical Engineering (in Chinese), 1999, 35(4): 67.
4. Popov, A. A., Pyshmintsev, I. Yu., Demakov, S. L., Structral and mechanical properties of nanocrystalline titanium processed by severe plastic deformation, Scripta Materialia, 1997, 37: 1089.
5. Jia, D., Ramesh, K. T., Ma, E., Failure mode and dynamic behavior of nanophase iron under compression, Scripta Materialia, 2000, 42: 73.

(Received June 5, 2000)