

# A Study of Local Nanocrystalline Structure of 0Cr16Ni22Mo2Ti Steel in Bond Area of Flash Welding

Zhang Fucheng\*, Zhang Ming and Li Jianhui

College of Materials Science and Engineering, Yanshan University, Qinhuangdao, 066004, P.R. China

A nanocrystalline layer was fabricated in bond area of 0Cr16Ni22Mo2Ti steel using flash welding. The average grain size near bond line is about 30 nm and the farther the distance from the bond line, the larger the size of the nanocrystallites. The thickness of the nanocrystalline layer is about 80  $\mu\text{m}$ . The formation mechanism of the nanocrystallites may be that the metal in liquid state in the bond area is solidified under both high undercooling and high density d.c. electric current that can refine the microstructure of metal solidification.

(Received March 18, 2002; Accepted May 13, 2002)

**Keywords:** nanocrystalline, high undercooling, high-density electric current, steel

## 1. Introduction

Nanocrystalline materials have attracted much attention because of their unusual properties and microstructures.<sup>1,2)</sup> In order to study the properties of the nanocrystalline phase, the preparation of a large bulk nanocrystalline material with clean grain boundaries and less porosity is of great importance to theoretical studies and practical applications. Many methods of producing bulk nanocrystalline material have been developed, however, it has been demonstrated that there are pores and even impurities at grain boundaries of the bulk nanocrystalline materials.<sup>3,4)</sup>

Recently, Guo *et al.*<sup>5)</sup> demonstrated that bulk, microvoid free nanostructured materials of relatively uniform grain size are prepared by fluxing technique and rapid solidification in  $\text{Pd}_{82}\text{Si}_{18}$  eutectic alloy. The application of an electric field during the solidification of materials has been found to have an influence on the microstructure of the resulting solid. In the case of metals, electro migration in the liquid produced substantial changes in composition due to differences in ionic mobility. Further, both a small, continuous d.c. current ( $\sim 0.1 \text{ A cm}^{-2}$ ) and high density ( $\sim 10^3 \text{ A cm}^{-2}$ ) electro pulsing refined the microstructure of castings.<sup>6)</sup>

High-speed rail demands the welding of ZGMn13 steel crossing with carbon steel rail. Many materials including 0Cr16Ni22Mo2Ti steel were chosen as welding materials and flash welding technology was employed for experiment. In studying the microstructures of the bond area, we found that the microstructure of 0Cr16Ni22Mo2Ti steel near the bond line was the nanocrystalline. This paper studies the nanocrystalline structures and discusses its formation mechanism.

## 2. Experimental

The experimental materials were 0Cr16Ni22Mo2Ti steel and ZGMn13 steel. The 0Cr16Ni22Mo2Ti steel was smelted in a vacuum induction furnace, 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 pressure. The welding thermal/mechanical conditions are as follows: heating speed is about  $30^\circ\text{C/s}^{-1}$ , heating temperature is about  $1400^\circ\text{C}$ , pressure is at 100 MPa, d.c. electric current density is at  $380 \text{ A cm}^{-2}$ , cooling rate around melt point temperature is about  $30^\circ\text{C/s}^{-1}$ . 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.

## 3. Results and Discussion

The microstructures of the 0Cr16Ni22Mo2Ti steel forged are of recrystallized equiaxial grains, and its grain size is about 60  $\mu\text{m}$ . The microstructures of the 0Cr16Ni22Mo2Ti steel in the bond area are shown in Fig. 1. It is found that the microstructure of the 0Cr16Ni22Mo2Ti steel is of nanocrystalline with fcc structure, its average size near the bond line is about 30 nm. Using transmission energy spectrum analysis, we find that in the nanocrystalline the content of alloying elements is Cr 15.8, Ni 21.7, Mo 1.9, which correspond to average chemical compositions of the 0Cr16Ni22Mo2Ti steel. In the bond area thickness of the nanocrystalline structure zone along the bond line is about 80  $\mu\text{m}$ . The farther the distance from weld junction, the larger the nanocrystalline size. 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 the nanocrystalline.

The formation reason of the nanocrystalline may be that in the process of the flash welding the bond area in the liquid state subjected to both high undercooling and high density d.c. electric current. The application of the high density d.c. current during freezing produced substantial changes in the solute distribution coefficient and in turn on the composition and microstructure on the solid. High density d.c. electric current can enhance the nucleation rate and fracture dendrites by the pinch effect during metal solidification.<sup>6)</sup> So it can refine the microstructure of castings obviously. In theory, a bulk nanocrystalline metal can be obtained when the elec-

\*Corresponding author: E-mail: zfc@ysu.edu.cn

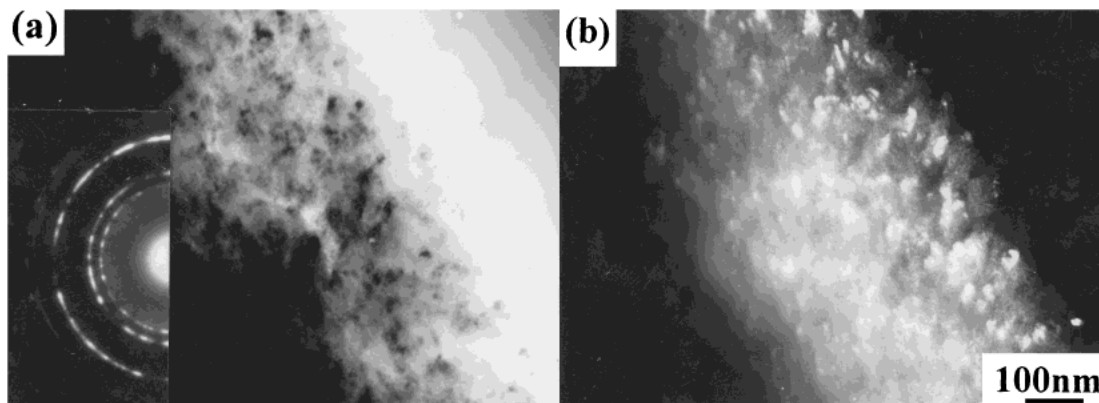


Fig. 1 Microstructures of bond area of 0Cr16Ni22Mo2Ti steel (a) light image and (b) dark image, the selected area electron diffraction pattern shows that microstructure is ultrafine crystalline with fcc structure.

tric current density is high as  $10^3 \text{ A cm}^{-2}$ .<sup>7)</sup> However, only little is known regarding the mechanism by which an electric current affects the solidification process. In the mean time, in the welding joint the temperature of the bond line is high, and its cooling rate is rapid (about  $30^\circ\text{C/s}$ ), it causes high undercooling. The high undercooling can also increase nucleation rate and decreasing growth rate during metal solidification.<sup>5)</sup> In addition, compared with the microstructure 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. Based on defining the formation mechanism of the nanocrystalline of the 0Cr16Ni22Mo2Ti steel, the bulk nanocrystalline materials can be made.

#### 4. Conclusions

A nanocrystalline layer with fcc structure was fabricated in bond area of 0Cr16Ni22Mo2Ti steel using flash welding.

The formation mechanism of the nanocrystalline may be that the metal in liquid state is solidified under both high undercooling and high-density electric current that can refine the microstructure of metal solidification obviously.

#### Acknowledgements

The work is supported by National Nature Science Foundation of China and Nature Science Foundation of Hebei Province. The project number is 50171057 and 501193 respectively.

#### REFERENCES

- 1) H. Gleiter: Prog. Mater. Sci. **33** (1989) 223.
- 2) K. Lu: Mater. Sci. Eng., Reports **16**, (1996) 161.
- 3) X. Y. Qi, W. J. Wu and R. S. Cheng: Nanostruct. Mater. **2** (1993) 99.
- 4) H. Hahn, J. Logas and R. S. Averback: J. Mater. Res. **5** (1990) 609.
- 5) W. H. Guo and H. W. Kui: Acta Mater. **48** (2000) 2117.
- 6) H. Conrad: Mater. Sci. Eng., **A287** (2000) 205.
- 7) H. C. Yan, G. H. He and B. L. Zhou: Acta Metall. Sinica **33** (1997) 352.