Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

Fabrication of nano-sized ceramic dispersed carbon steel by liquid metal casting process

Jin-Ju Park [a*], Sung-Mo Hong [a,b], Eun-Kwang Park [a], Kyoung-Youl Kim [a,c], Min-Ku Lee [a], Chang-Kyu Rhee [a]
[a]*Nuclear Materials Development Division, Korea Atomic Energy Research Institute, Daejeon*
[b]*Division of Advanced Materials Engineering, Kongju National University, Cheonan*
[c]*Department of Materials Science and Engineering, Chungnam National University, Daejeon*
[*]*Corresponding author: jinjupark@kaeri.re.kr*

1. Introduction

One of the new methods for microstructure refinement and correspondingly improvement of the mechanical properties of alloys is the modification with nano- and micro-sized particles [1-3]. Micron-sized ceramic particles as nitride, carbides, or borides are widely used to improve the strength of metal matrix composite materials, though they often deteriorate the ductility of these composites. On the other hand, nanoparticles reinforcement can significantly increase the matrix mechanical strength by more effectively promoting particle hardening mechanism than micro-sized particles. As a result, metal matrix nano-composites (MMNCs) have been the subject of intense study for the last decade. The aim of this study is to disperse nano-sized TiC ceramic particles below 50nm in a carbon steel matrix through the use of a conventional liquid metal casting process. Changes in the microstructure and mechanical properties of the matrix are discussed with respect to the addition of nano-sized TiC ceramic particles.

2. Methods and Results

2.1 Experimental methods

Carbon steel A106B was selected as matrix material widely used at the secondary cooling system of NPP. The cast ingots of the carbon steel were produced by a 50kg-capacity (medium) frequency vacuum induction furnace. When the base pressure within the body of the furnace reached about 8×10^{-2}Pa, high purity (99.99%) argon gas was introduced into the furnace to 0.05MPa. And then the starting materials were heated until melting. The applied heating rate was about 80^{o}C min^{-1}. After melting the starting materials, nano-sized TiC ceramic particles containing composite modifier powders encapsulated with carbon steel were introduced onto the melt [4]. The melt was maintained for 5min and then poured into a metallic mold with dimension of thickness of 80mm. Subsequently, the ingots were hot rolled to 32 mm thick at 1150^{o}C. And then they were cold rolled to 25 mm thick at ambient temperature. Finally, the cold rolled carbon steels were heat treated at 920^{o}C for 30min.

The microstructural properties and the dispersion of the TiC particles in the samples were observed via optical microscopy, EBSD and SEM. The Brinell and tensile tests assessed the hardness and strength of the cast carbon steel with respect to the added nano-sized TiC particles.

2.2 Microstructural changes

The macrostructures after solidification for as-cast carbon steel and modified one by the introduction of TiC particles below 50nm were presented in Fig. 1. It is widely known that cast structure after solidification is mainly consisted of outer columnar zone and inner equiaxed one. From the figure, it was readily found that the fraction of equiaxed zone for the modified cast carbon steel increased by about 2 times compared to that for as-cast one, expecting the promotion of formability and workability of cast ingot by the addition of TiC nanoparticles in the matrix. The increase in the fraction of equiaxed zone is probably due to the fact that TiC nanoparticles act as nucleation sites during the solidification process. As a result, the solidification rate of carbon steel matrix distributed with TiC nanoparticle exceeds that of columnar zone, resulting in the increase of equiaxed zone by the addition of TiC nanoparticles.

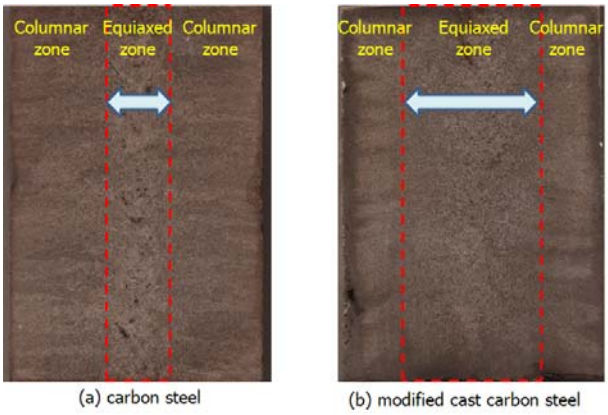

Fig. 1. Optical image of macrostructure after solidification for (a) carbon steel and (b) modified one by the introduction of TiC particles below 50nm in size.

Fig. 2 gives optical microstructural images and EBSD analyses results of as-cast carbon steel and modified cast one after hot rolling process and the subsequent normalizing heat treatment. The grain size of the modified carbon steel decreased drastically compared to that of cast carbon steel. In order to clarify this grain size refinement quantitatively, metallographic analysis was done for optical microstructural images by the help of EBSD method. As a consequence, the average areas of the grains were measured to 102.66μm^2 and 67.37μm^2 for both carbon steel and modified one, respectively. From this result, the values of equivalent circle diameters meaning the average grain size were calculated to be 11.4μm and 9.3μm for both carbon steel and modified one, respectively.

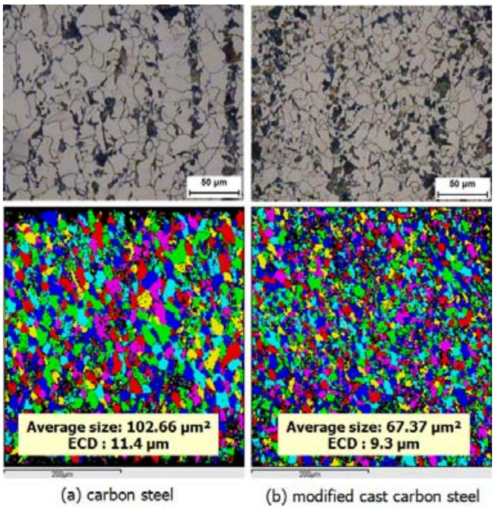

Fig. 2. Optical microstructural image of (a) carbon steel and (b) modified one by the addition of nano-sized TiC particles and the corresponding EBSD analyses results.

2.3 Mechanical properties

The mechanical tests were carried out at room temperature to compare the mechanical properties of modified steel with as-cast one. Table I shows the values of Brinell hardness, yield strength, tensile strength and elongation of carbon steel and modified one. Because very fine harder TiC particles are distributed in the matrix in the matrix, the hardness value of modified carbon steel increased by 10% compared to that of non-modified carbon steel. In addition, the values of the tensile and yield strength were also increased by the addition of TiC nano-particles. The value of elongation was slightly decreased by the addition of TiC nano-particles. From the mechanical properties, it is expected that the addition of TiC nano-particles may distribute homogeneously and therefore have a positive effect on the mechanical properties.

Table I: Hardness and tensile test results.

	As-cast carbon steel	Modified cast carbon steel
Brinell hardness (HB)	150	166
Yield strength (MPa)	336	380
Tensile strength (MPa)	531	568
Elongation (%)	36.4	35.5

3. Conclusions

In this work, nano-sized TiC ceramic particles below 50nm are successfully dispersed into the carbon steel by a conventional liquid metal casting process. In order to disperse nano-sized TiC ceramic particles, TiC ceramic particles is modified and introduced into the molten metal. Optical microscopic images reveal that TiC particles are distributed uniformly in the cast carbon steel matrix, leading to the grain size refinement. The addition of nano-sized TiC particles improves the mechanical properties at room temperature without drastic reduction in fracture toughness. From the experimental results, by the help of our own method for the synthesis of modifying powder, the present work proposes that a conventional casting process can be an effective way to fabricate ODS alloys.

REFERENCES

[1] K.M. Mussert, W.P. Vellinga, A. Bakker, S. Zwaag, A nano-indentation study on the mechanical behavior of the matrix materials in an AA6061-Al_2O_3 MMC, Journal of Materials Science, Vol.37, p.789, 2002.
[2] R. Zhong, H. Cong, P. Hou, Creep of metal composites reinforced by combining nano-sized dispersions ewith micro-sized ceramic particulates or whiskers, Carbon, Vol.47, p.848, 2003.
[3] Y. Yang, J. Lan, X. Li, Study on bulk aluminum matrix nano-composite fabricated by ultrasonic dispersion of nano-sized SiC particles in molten aluminum alloy, Materials Science & Engineering A, Vol.380, p.378, 2004.
[4] S.H. Lee, S.M. Hong, B.S. Han, J.J. Park, J.K. Lee, J.G. Lee, M.K. Lee, C.K. Rhee, Homogeneous dispersion of TiC nano particles in a cast carbon steel matrix, Journal of Nanoscience and Nanotechnology, Vol. 10, p.258, 2010.