Carbide Structure and Fracture Toughness of High Speed Tool Steels

Jung-Ho Moon, Tae Kwon Ha

Abstract**—**In the present study, M2 high speed steels were fabricated by using electro-slag rapid remelting process. Carbide structure was analysed and the fracture toughness and hardness were also measured after austenitization treatment at 1190 and 1210°C followed by tempering treatment at 535°C for billets with various diameters from 16 to 60 mm. Electro-slag rapid remelting (ESRR) process is an advanced ESR process combined by continuous casting and successfully employed in this study to fabricate a sound M2 high speed ingot. Three other kinds of commercial M2 high speed steels, produced by traditional method, were also analysed for comparison. Distribution and structure of eutectic carbides of the ESRR billet were found to be comparable to those of commercial alloy and so was the fracture toughness.

Keywords**—**High speed tool steel, eutectic carbide, microstructure, hardness, fracture toughness.

I. Introduction

HIGH speed steel, widely used for machining tools, is characterized of excellent hardness, wear resistance, and high temperature properties. The name – high speed steel – is a synthesis of the following two features: (a) the alloys belong to the Fe-C-X multicomponent system, where X represents a group of alloying elements in which Cr. W or Mo, V, and Co are the principal ones; (b) the alloys are characterized by their capacity to retain a high level of hardness even when submitted to elevated temperatures resulting from cutting metals at high speed [1], [2].

The toughness of high speed steel is a property of considerable practical importance and generally implies some measure of the ability of the steel to absorb impact leads without significant macroscopic plastic deformation or catastrophic failure [3]. A cutting tool which is required to maintain precise dimensional tolerances, frequently under conditions of intermittent cutting involving repeated impact loading, cannot be permitted any large amount of irreversible deformation. For this reason, ductility alone is of questionable significance as a criterion of adequate tool performance. It is generally agreed that toughness of high speed steels is an important property. The influence of such structural parameters as grain size as well as the morphology and distribution of carbides on toughness is very crucial.

J. Moon is with the Department of Electronics Engineering, Gangneung-Wonju National University, 120 Gangneung-daehangno, Gangneung, Gangwon 210-702, South Korea.
T. K. Ha is with the Department of Advanced Metal and Materials Engineering, Gangneung-Wonju National University, 120 Gangneung-daehangno, Gangneung, Gangwon 210-702, South Korea (phone: 82-10-2367-1989; e-mail: tkha@gwnu.ac.kr).

High speed steels produced by electro-slag rapid remelting (ESRR) process provide better end-use performance than those produced from conventionally cast ingots [4]. The advantage of ESRR steels is related to the absence of regions exhibiting greater concentration of eutectic colonies (as is typical in conventional ingots) and, consequently, of thicker stingers in the microstructure after plastic deformation.

In the present study, ESRR process was employed to fabricate billets of M2 high speed steel. After austenitization heat treatment at 1190 and 1210°C followed by tempering treatment at 535°C for billets with various diameters from 16 to 60 mm, distribution and structure of eutectic carbides of the billets were analysed and cleanliness, hardness, and fracture toughness of the billets were also evaluated. For comparison, three types of commercial M2 high speed steels were also analysed in this study.

II. Experimental Procedures

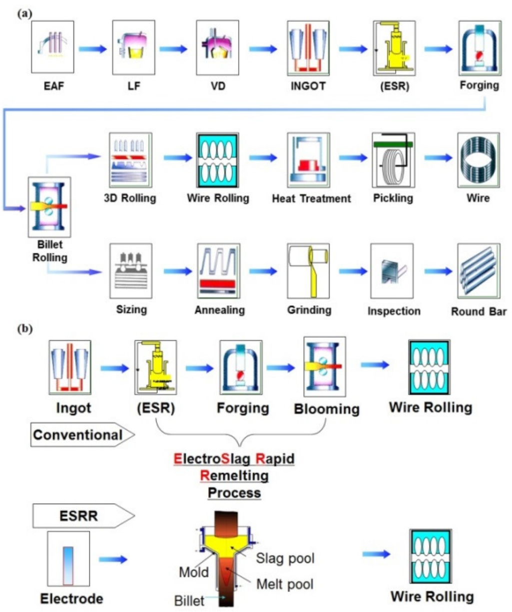

Fig. 1 Illustration of traditional (a) and ESRR (b) processes used for production of HSS products [5]

Schematic illustration of ESRR process is given in Fig. 1 together with conventional process for fabrication of high speed steels. By remelting a consumable electrode in a superheated slag bath, a new ingot is built up in water-cooled copper mold.

Ingots of M2 high speed steel were fabricated with melting power of 1100~1350kwh/ton, melting rate of 400~700kg/h, and electrode weight of 1.6 ton. Cleanliness of ESRR ingots was evaluated. Distribution and microstructure of carbides were also observed by OM and SEM. After austenitization heat treatment at 1190 and 1210°C followed by tempering treatment at 535°C for billets with various diameters from 16 to 60 mm, distribution and structure of eutectic carbides of the billets were analysed and cleanliness, hardness, and fracture toughness of the billets were also evaluated. For comparison, three types of commercial M2 high speed steels, designated by H, B and N in this study, were also analysed in this study. Billet fabricated in this study was designated by C.

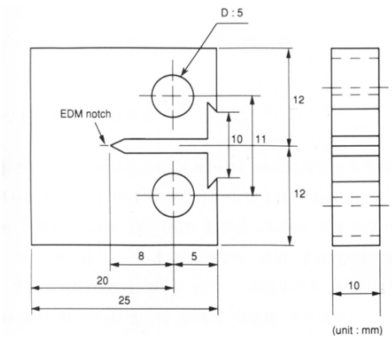

Fig. 2 Shape and dimensions of CT specimen used in this study

The apparent fracture toughness was obtained from a compact-tension (CT) type specimen having a sharp notch. It has been reported that the apparent toughness measured form the sharp notched CT specimen is found to be almost equivalent to the plane strain fracture toughness (K_{IC}) in a brittle materials such as ultrahigh-strength steels [6], [7]. As shown in Fig. 2, a sharp notch of 35 to 40 μm in tip radius was introduced into the CT specimen using an electrodischarge machine [6]. Test and data-interpretation procedures followed ASTM E399 [8] specifications. The stress-intensity-factor rate was about 1MPa √m/s in this study.

Fig. 3 Appearance of ESSR billet of M2 steel fabricated in this study

III. Results and Discussion

An appearance of ESRR billet of M2 HSS is given in Fig. 3. Fabricated billets are all in good condition not only outside but inside. Dimensions of produced billets were 200 mm × 200 mm × 6 m. Cleanliness of ESRR billets was also much higher than those of the traditional ingots.

Figs. 4 and 5 show carbide distribution and structure of high speed steels with diameter of 60 mm analyzed in the surface and center part of the billet, respectively. The billet produced by N company shows most uniform distribution and size of carbides. Carbide structure and distribution of the billet fabricated in this study are basically comparable to the other two billets H and B. It is well known that, for a given cooling rate, the greater the thermal gradient in the liquid phase, the greater the fraction of columnar grains in the macrostructure [9].

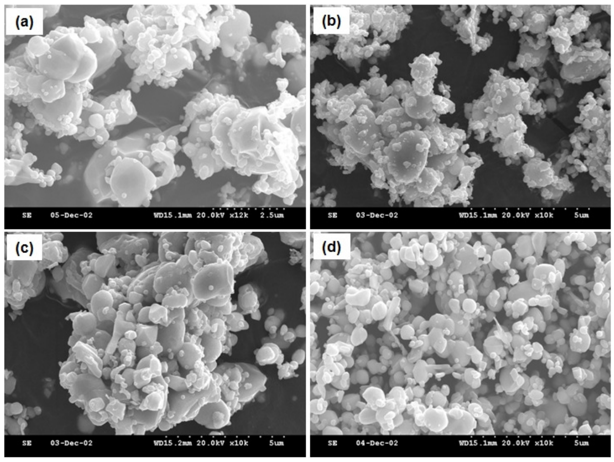

Fig. 4 Distribution and structure in the surface part of M2 high speed steel billet with diameter of 60 mm fabricated in this study (a), H (b), and B (c), and N (d) companies, respectively

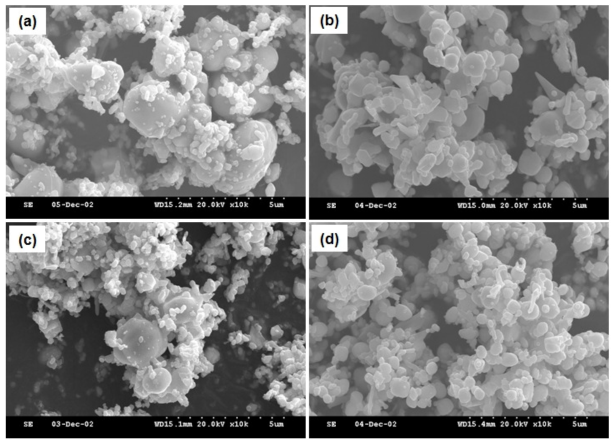

Fig. 5 Distribution and structure in the center part of M2 high speed steel billet with diameter of 60 mm fabricated in this study (a), H (b), and B (c), and N (d) companies, respectively

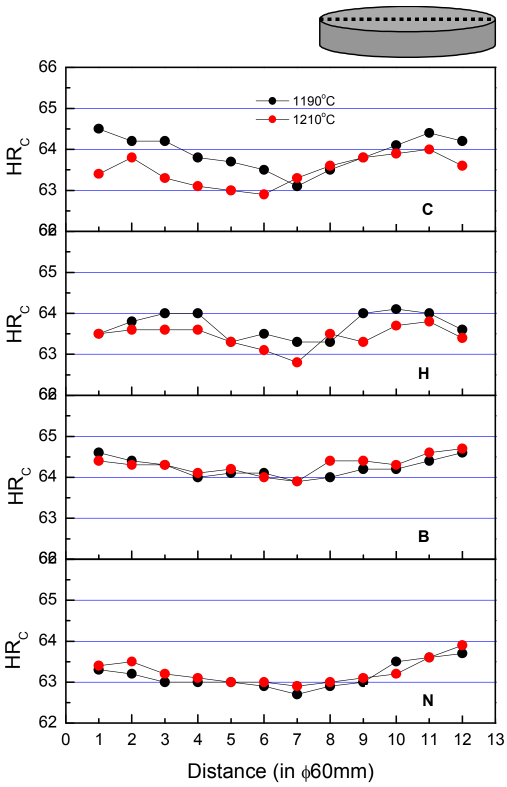

Fig. 6 Hardness distribution of the high speed steel billets fabricated in this study and by various companies

Composition profiles of C and Mo were very uniform throughout the diagonal distance from the corner surface except center of the billet. Hot rolling was also successfully conducted to obtain 20 mm thick plates.

Fig. 6 shows hardness distribution of high speed steel billets with diameter of 60 mm austenitized at 1190 and 1210°C. The hardness level of the billet treated at 1190°C is a little higher than that of the billet treated at 1210°C for C and H samples, while the hardness of B and H were found to be not affected by austenitization temperatures. Considering the hardness level and distribution, M2 high speed steel of B is most uniform. Fig. 7 shows hardness distribution of high speed steel billets with diameter of 16 mm austenitized at 1190 and 1210°C. Interestingly, distribution and level of hardness is most uniform in the billet fabricated by this study.

The results of apparent fracture toughness of the M2 high speed steels with diameter of 60 mm are shown in Fig. 8. Fracture toughness of M2 steel fabricated in this study was obtained as higher level at the surface region than the other products after austenitization treatment at 1190°C (Fig. 8 (a)) and at the center region after treatment at 1210°C (Fig. 8 (b)). It is interesting to note that toughness at the center region after austenitization at 1210°C is very high comparable to that of H sample as shown in Fig. 8 (b). From the figures, it has been approved that fracture toughness is not closely related to the sampling position nor structure and distribution of carbides.

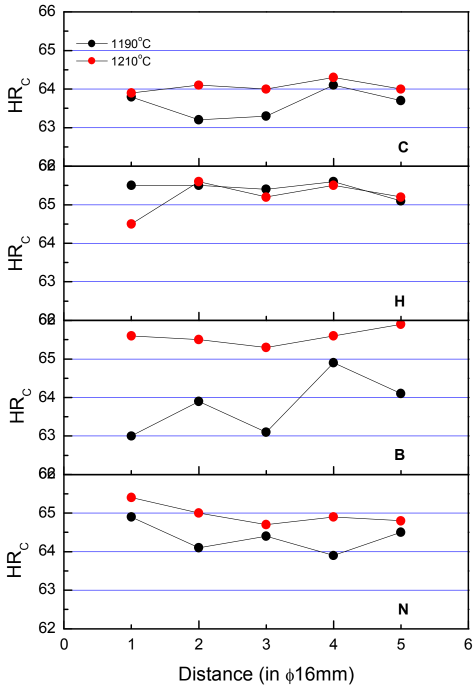

Fig. 7 Hardness distribution of the high speed steel billets fabricated in this study and by various companies

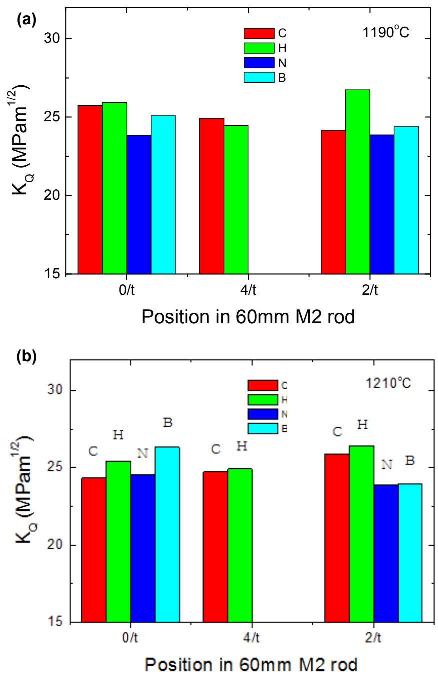

Fig. 8 Profiles of fracture toughness of the M2 billets austenitized at 1190°C (a) and 1210°C (b)

IV. Conclusions

In the present study, billets of M2 high speed steel were successfully produced by employing ESRR process. On the billets, austenitization heat treatment was conducted at temperatures of 1190 and 1210°C followed by tempering treatment at 535°C. Distribution and structure of eutectic carbides of the billets were analysed and fracture toughness of the billets were also evaluated. Carbide structure and distribution of the billet fabricated in this study are basically comparable to the other commercial steels. Fracture toughness of M2 steel fabricated in this study was obtained as higher level at the surface region than the other products after austenitization treatment at 1190°C and at the center region after treatment at 1210°C. Three commercial M2 high speed steels were also analysed in this study. Fracture toughness was found to be not closely related to the sampling position nor structure and distribution of carbides.

ACKNOWLEDGMENT

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