

# Alloying Effect on Hot Workability of M42 High Speed Steel

Jung-Ho Moon, Tae Kwon Ha

**Abstract**—In the present study, the effect of Si, Al, Ti, Zr, and Nb addition on the microstructure and hot workability of cast M42 tool steels, basically consisting of 1.0C, 0.2Mn, 3.8Cr, 1.5W, 8.5Co, 9.2Mo, and 1.0V in weight percent has been investigated. Tool steels containing Si of 0.25 and 0.5wt.%, Al of 0.06 and 0.12wt.%, Ti of 0.3wt.%, Zr of 0.3wt.%, and Nb of 0.3wt.% were cast into ingots of 140mm × 140mm × 330mm by vacuum induction melting. After solution treatment at 1150°C for 1.5hr followed by furnace cooling, hot rolling at 1180°C was conducted on the ingots. Addition of titanium, zirconium and niobium was found to retard the decomposition of the eutectic carbides and result in the deterioration of hot workability of the tool steels, while addition of aluminum and silicon showed relatively well decomposed carbide structure and resulted in sound hot rolled plates.

**Keywords**—High speed steels, alloying elements, eutectic carbides, microstructure, hot workability.

## I. INTRODUCTION

HIGH speed steels are developed largely for use in high speed cutting tool applications. The cutting ability depends on a combination of the four most important properties, such as hardness, hot hardness, wear resistance, and toughness [1]. The requirements for hardness, wear resistance, hot hardness, and toughness determine the exact chemical compositions. High-speed tool steels usually contain sufficient carbon to permit hardening to 64 HR<sub>C</sub> and harden so deeply that a part has a uniform hardness from center to surface [2], [3].

There are two classifications of high speed steels: molybdenum high speed steels, also called group M, and tungsten high speed steels, also called group T. A subgroup in the M group consists of intermediate high speed steels. Group M and group T high speed steels are equivalent in performance. The main advantage of group M steels is lower initial cost, approximately 40% lower than that of similar group T steels. This difference in cost results from the lower atomic weight of Mo, which is about a half that of W. Steels of M40 series are used to make cutting tools for machining very tough and advanced high strength steels [4].

Molybdenum high speed steels contain Mo, W, Cr, V, Co, and C as principal alloying elements. They possess excess carbide particles, which in the annealed state contain a high proportion of the alloying elements. By partially dissolving

during heat treatment, these carbides provide the matrix of the steel with necessary alloy and carbon content for hardenability, hot hardness, and resistance to tempering.

M42 steels have unusually high resistance to softening at elevated temperature as a result of high alloy content. The various stages of manufacturing process are chosen and controlled so that an end product is obtained with a good structure in terms of carbide size and distribution. In terms of performance, M42 steels are used in conditions where the demand for hot hardness is of great importance [4].

The fabrication of wrought high-speed steels mainly consists of melting, casting, hot working, and heat treatment processes. Proper heat treatment is as critical to the success of cutting tool as material itself. The object of the heat treatment and hardening operation is to transform fully annealed state, mainly of ferrite with carbides, into a hardened and tempered martensitic structure having carbides that provide the cutting tool properties [5]. In the present study, the influences of alloying elements such as Si, Al, Zr, Ti, and Nb on the hot workability and microstructural evolution of M42 high speed steel were investigated.

## II. EXPERIMENTAL PROCEDURES

The ingots of M42 high-speed tool steel were cast by vacuum induction melting (VIM) into the ingots with dimensions of 140mm × 140mm × 330mm. The chemical compositions of the ingots were summarized in Table I.

TABLE I  
CHEMICAL COMPOSITIONS OF THE INGOTS PRODUCED IN THIS STUDY (WT.%)

Ingot	C	Mn	Cr	W	Co	Mo	V	Si	Element added
S0	1.0	0.2	3.8	1.5	8.5	9.2	1.0	0.3	-
S1	1.0	0.2	3.8	1.5	8.5	9.2	1.0	0.5	-
A1	1.0	0.2	3.8	1.5	8.5	9.2	1.0	0.3	0.06Al
A2	1.0	0.2	3.8	1.5	8.5	9.2	1.0	0.3	0.12Al
Z1	1.0	0.2	3.8	1.5	8.5	9.2	1.0	0.3	0.3Zr
T1	1.0	0.2	3.8	1.5	8.5	9.2	1.0	0.3	0.3Ti
N1	1.0	0.2	3.8	1.5	8.5	9.2	1.0	0.3	0.3Nb

The ingots with silicon contents of 0.3 and 0.5 in weight percent were designated by S0 and S1 respectively, where S0 is base composition of M42 high speed steel. The designations A1, A2, Z1, T1, and N1 are denoting ingots with 0.06Al, 0.12Al, 0.3Zr, 0.3Ti, and 0.3Nb added to base compositions of S0. The ingots were solution heat treated at 1150°C for 1.5hr followed by furnace cooling. Subsequently, hot rolling was conducted on longitudinally halved ingots at 1180°C after soaking for 2 hours into 15mm thick plates. Microstructure observation was carried out on the ingots and the hot rolled plates.

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### III. RESULTS AND DISCUSSION

Fig. 1 shows appearances of the ingot S0 just before and during hot rolling and Fig. 2 shows results of hot rolling of the ingots S0 and S1. From the Fig. 2, although some side cracks are observed, hot rolling was successfully conducted on both ingots. Actually ingot S0 is typical M42 high speed steel and S1 contains increased Si content, which has not affected hot workability of M42 steel.

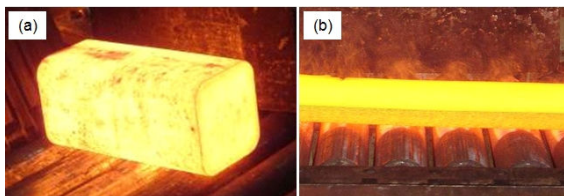


Fig. 1 Appearances of the ingot S0 before (a) and during (b) hot rolling

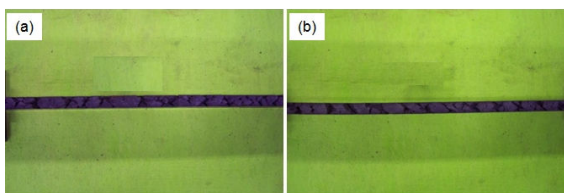


Fig. 2 Appearances of the ingots (a) S0 and (b) S1 after hot rolling

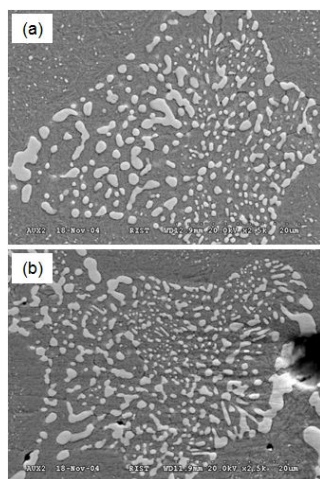


Fig. 3 SEM micrographs showing appearances of eutectic carbides of the ingots (a) S0 and (b) S1 after solution treatment at 1150°C for 1.5 hr before hot rolling

Fig. 3 shows SEM micrographs showing appearances of eutectic carbides of the ingots S0 and S1, respectively, after solution treatment. As the silicon content increases, it is apparent that the eutectic carbides are coarsened a little but the extent is not noticeable. The degree of spheroidization of eutectic carbide is very high, even after the solution treatment at 1150°C, which is attributed to relatively good hot rolling results [6] illustrated in Fig. 2.

It is well known that silicon enters the matrix, where it replaces W, Mo and V. It has a similar, additive, effect to that of

nitrogen, raising the solubility of carbon in the matrix and hence the as-quenched hardness. In the carbide phase, Si can enter the  $M_6C$  lattice, replacing up to one-sixth of the metal (M) atoms giving a general formula up to  $M_5SiC$  and cause the lattice parameter of the carbide to increase [7]. Also silicon tends to reduce the stability of  $M_2C$  carbide particles, accelerating their transformation to the  $M_6C$  type carbides that are preferred in final structures because of their rounded shape. The  $M_2C$  carbide particles occur in rod-like patterns, which can be advantageous in the formation of feathery eutectic, where the subsequent transformation to  $M_6C$  helps break up the eutectic networks [8].

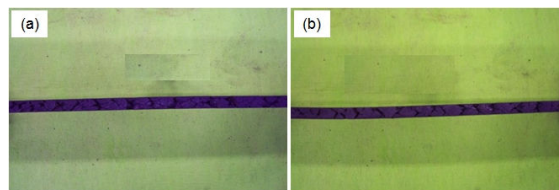


Fig. 4 Appearances of the ingots (a) A1 and (b) A2 after hot rolling

Fig. 4 shows results of hot rolling of the ingots A1 and A2. As similar to the results of Fig. 2, although some side cracks occurred hot rolling was successfully conducted on both ingots. Addition of aluminum up to 0.12wt.% appeared not to affect hot workability of M42 steel.

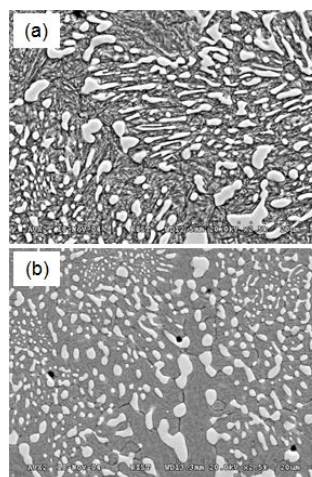


Fig. 5 SEM micrographs showing appearances of eutectic carbides of the ingots (a) A1 and (b) A2 after solution treatment at 1150°C for 1.5 hr before hot rolling

Fig. 5 shows SEM micrographs showing appearances of eutectic carbides of the ingots A1 and A2, respectively, after solution treatment. The degree of spheroidization of eutectic carbide is very high, regardless of aluminum content after the solution treatment at 1150°C, which presumably resulted in hot rolled plate in good condition. As well known, aluminum plays important role to prevent decarburization at the surface by formation of protecting layer during hot rolling [2].

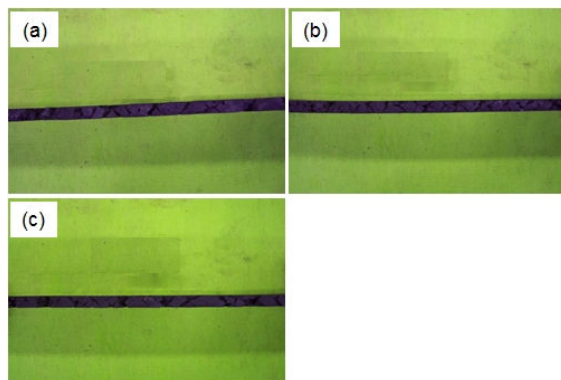


Fig. 6 Appearances of the ingots (a) T1, (b) Z1 and (c) N2 after hot rolling

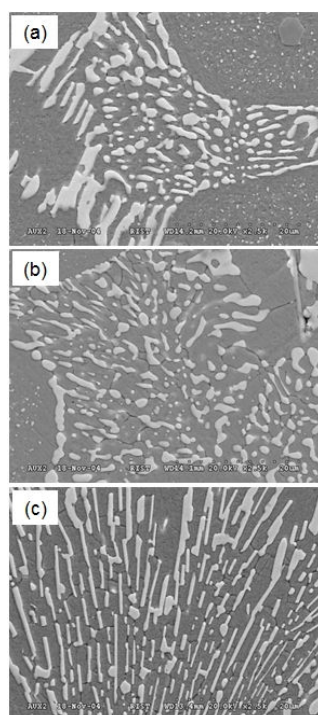


Fig. 7 SEM micrographs showing appearances of eutectic carbides of the ingots (a) T1, (b) Z1 and (c) N2 after solution treatment at 1150°C for 1.5 hr before hot rolling

Fig. 6 shows results of hot rolling of the ingots T1, Z1 and N2. Unlike the results of Fig. 2, it is noted that side cracks are severely formed. Additions of Ti, Zr, and Nb by 0.3wt.% appeared deteriorate hot workability of M42 steel.

Relatively coarser eutectic carbides shown in Fig. 7 are well known to cause serious problem during hot rolling process [9]. It is apparent that the degree of spheroidization of eutectic carbide is very low in all cases. Due to the fact, side cracks dramatically increased to make hot rolling more difficult. Side cracks can be reduced by decomposition of eutectic. In the case of low silicon content, i.e. the ingotS0, eutectic carbides were successfully decomposed during solution treatment, carbide particles are effectively rearranged along the tensile axis.

Otherwise, the specimen of N1 shows large cracks in the networks of eutectic carbides, not decomposed during solution treatment. Strong carbide forming elements, such as Ti, Zr, and Nb can favorably make MC type carbide. Especially, TiC can act as heterogeneous nuclei for the crystallization of MC carbide particle and, therefore, promote the formation of blocky MC carbide [10].

#### IV. CONCLUSIONS

With the addition of silicon and aluminum, the eutectic carbides formed on solidification of M42 high-speed steel were effectively decomposed into spheroidized particles by solution treatment at 1100°C for 1.5hr and hot rolling was successfully carried out at 1180°C. On the other hand, the addition of titanium, zirconium, and niobium was found to retard the decomposition of the eutectic carbides and result in the deterioration of hot workability of the tool steels.

#### ACKNOWLEDGMENT

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