논 문

# Effect of Si Content on the Microstructure of Cast M42 Tool Steel

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## Abstract

공구강은 C, Cr, V, Mo, W, Co 및 Si 과 같은 첨가원소를 함유한 복잡한 철계 합금으로 주요 특성인 경도, 부식저항성, 열연화저항성 그리고 인성의 요구수준에 따라 화학성분이 결정된다. 본 연구에서는 1.0C, 0.2Mn, 3.8Cr, 1.5W, 8.5Co, 9.2Mo, 1.0V 조성의 M42 공구강의 미세조직과 열간가공성에 미치는 Si 함량의 효과를 체계적으로 조사하였다. 진공유도용해를 이용하여 Si 함량을 중량비로 0.33 에서 1.7% 까지 변화시켜 140 × 140 × 330 mm$^3$ 크기의 잉곳으로 제조하였다. 이렇게 제조한 잉곳들은 1150°C 에서 1.5 시간 동안 용체화처리한 후 노냉하였고, 이어 1180°C 에서 15 mm 두께의 판재로 열간압연하였다. 공정탄화물의 형상 및 분해거동을 중심으로 미세조직을 관찰한 결과 Si 함량이 증가함에 따라 분해속도가 느려지는 것을 알 수 있었고 이로 인해 열간성형성이 급격히 저하되는 것으로 나타났다.

Key words : M42 Tool Steel, Si Content, Eutectic Carbides, and Hot Workability.

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## 1. Introduction

High-speed tool steels have ability to machine materials at high cutting speeds. The cutting ability depends on a combination of the four most important properties, such as hardness, hot hardness, wear resistance, and toughness [1]. High-speed tool steels are complex iron-base alloys of carbon, chromium, vanadium, molybdenum, tungsten and other minor elements such as silicon and cobalt. 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 $HR_C$ and harden so deeply that a part has a uniform hardness from center to surface [2,3]. 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 is conventionally manufactured cobalt alloyed high-speed tool steel. 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. M42 is, therefore, suitable for cutting tools such as, twist drills, broaches, taps, milling, cutters, saws, reamers etc. In terms of performance, M42 is a steel to be used in conditions where the demand for hot hardness is of great importance i.e. where high performance is essential [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 silicon on the microstructural evolution during heat treatment of M42 high-speed tool steels and hot workability were investigated by varying Si content from 0.33 to 1.70wt.% in the light of optimizing distribution of eutectic carbides.

## 2. Experimental

The ingots of M42 high-speed tool steel were cast by vacuum induction melting (VIM) into the ingots with dimensions of 140 mm×140 mm×330 mm. The chemical compositions of the ingots were summarized in Table 1, in which the silicon content is easily noted in the range from 0.33 to 1.70 in weight percent. The ingots were solution heat treated at 1150°C for 1.5 hr followed by furnace cooling. Tensile tests were performed at the ram speed of 10 mm/s and at temperatures ranging from 900 to 1200°C to evaluate

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**Table 1.** Chemical compositions of M42 high-speed tool steels used in this study. (wt.%)

| Alloy | C | Si | Mn | Cr | W | Co | Mo | V |
|---|---|---|---|---|---|---|---|---|
| A | 1.20 | 0.33 | 0.19 | 3.82 | 1.54 | 8.91 | 9.15 | 0.94 |
| B | 1.21 | 0.68 | 0.19 | 3.64 | 1.48 | 8.52 | 9.20 | 0.99 |
| C | 1.22 | 1.36 | 0.19 | 3.73 | 1.50 | 8.51 | 9.51 | 0.99 |
| D | 1.10 | 1.70 | 0.19 | 3.68 | 1.46 | 8.66 | 9.24 | 0.96 |

the hot workability of the ingots, using the Gleeble testing machine. The dimensions of the tensile specimens were 10 mm in diameter and 120 mm in gage length. Subsequently, hot rolling was conducted on longitudinally halved ingots at 1180°C after soaking for 2 hrs into 15 mm thick plates. Microstructure observation was also carried out on the ingots, specimens fractured by tensile tests and the hot rolled plates.

## 3. Results and Discussion

Figure 1 is SEM micrograph showing appearances of eutectic carbides of M42 high-speed tool steels, after solution treatment, with various Si contents. As the content of silicon increases, it is apparent that the eutectic carbides are noticeably coarsened and the degree of decomposition of them is very low, even after the solution treatment at 1150°C. Flow curves obtained from high temperature tensile tests conducted at 1100°C are shown in Fig. 2, revealing that strain of the M42 high-speed tool steel decreases with increasing Si contents. It is interesting to note that the effect of Si contents on the tensile strength is negligible.

The coarse eutectic carbides are well known to cause serious problem during hot rolling process [6,7]. Figure 3 shows appearances of hot rolled plates with various silicon contents. With the increase in Si content, side-cracks dramatically increased so that hot rolling itself could not be done when the silicon content was 1.36wt.%. Side-cracks can be reduced by decomposition of eutectic carbides as shown in the SEM micrographs of Fig. 4, which were taken near the fracture tips of tensile specimens tested at

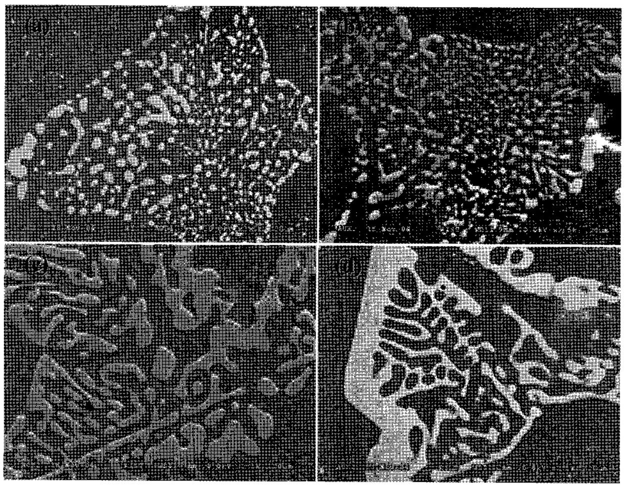

Fig. 1. SEM micrographs showing appearances of eutectic carbides of M42 high-speed tool steels with Si contents of (a) 0.33, (b) 0.68, (c) 1.36, and (d) 1.70wt.%, respectively.

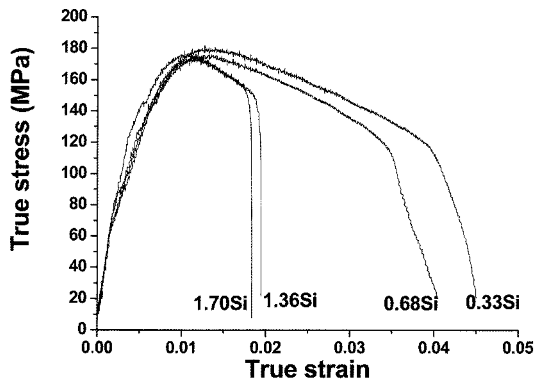


Fig. 2. Flow curves obtained from tensile tests conducted on M42 tool steels with various Si contents at 1100°C.

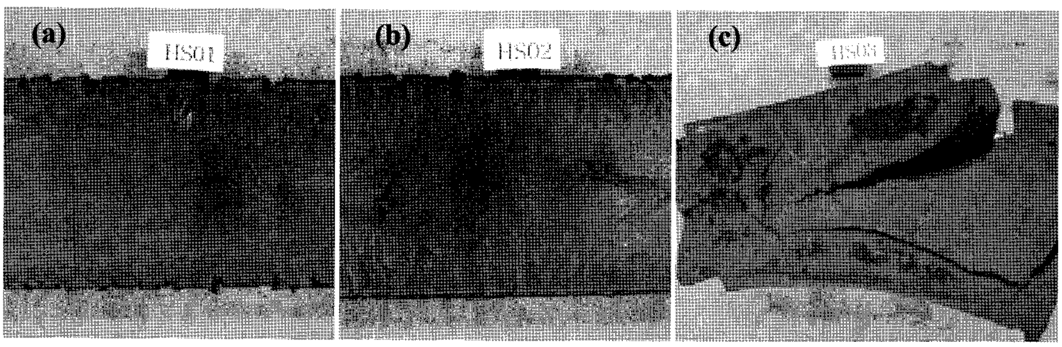


Fig. 3. Appearances of hot rolled plates with various silicon contents of (a) 0.33, (b) 0.68, and (c) 1.36wt.%.

temperature of 1100°C. In the case of low silicon content (0.33wt.% Si) where eutectic carbides were successfully decomposed during solution treatment, it is easily noted that carbides particles are effectively rearranged along the tensile axis. However, the specimen of high silicon content shows large cracks in the networks of eutectic carbides, not decomposed during solution treatment.

The normal silicon content of high-speed tool steel is in the range of 0.3% but optimum content of silicon is still controversial. In the range 0.3 to 1.5%, silicon is reported to raise the secondary hardness. It is claimed that toughness is not impaired up to about 1% but above this level there appears to be some doubt. It is suggested that the higher hardness is achieved at lower austenitizing temperature, and with refined grain size, in the range 0.5-1.0% Si, and that the secondary hardening peak occurs at a lower temperature. Each 1% Si lowers the solidus temperature by 3°C [4].

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 [8,9]. 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 [10]. It does not appear to be suggested that the formation of $M_2C$ on solidification is inhibited by silicon, but it is observed that this carbide is not present in the solidified structure at the higher silicon levels.

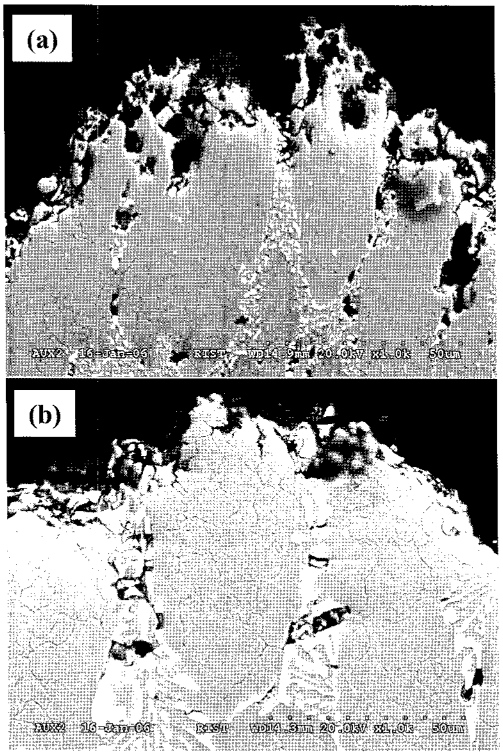


Fig. 4. SEM micrographs taken near the fracture tips of tensile specimens with silicon contents of (a) 0.33 and (b) 1.36wt.%, respectively, tested at temperature of 1100°C.

## 4. Conclusions

1) With the increase in silicon content, the eutectic carbides formed on solidification of M42 high-speed tool steel were found to coarsen dramatically.

2) The increase in silicon content of M42 high-speed tool steel appeared to retard decomposition of eutectic carbides.

3) The increase in silicon content of M42 high-speed tool steel seriously deteriorated hot workability due to the coarse eutectic carbides barely decomposed during heat treatment.

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