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ANISOTROPIC DIMENSIONAL CHANGE OF SKD11 TOOL STEEL DURING HARDENING AND TEMPERING HEAT TREATMENT[1]

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Abstract
Forged and flat-bar rolled SKD11 tool steels are known to show anisotropic dimensional change during heat treatment. In this study, the continuous dimensional change and the anisotropic behavior of SKD11 tool steel during austenitizing and tempering heat treatment have been investigated by dilatometry. Anisotropic dimensional change occurs not during heating but mostly during cooling, and it increases with increasing austenitizing temperature. Anisotropic dimensional change of SKD11 tool steel was mainly attributed to large elongated carbides produced during rolling process. Using dilatometric and metallographic examination, the possible mechanism of the anisotropic dimensional change has been discussed.
Key words: Anisotropic distortion; SKD11 tool steel; Dimensional change; Dilatometry.

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1 INTRODUCTION

SKD11 is one of the most popular cold work die steels widely being applied in many industrial areas such as automotive, electronic and other industries especially for punching and forming operation, because it has high strength, high wear resistance and good toughness. This tool steel is often called non-deforming steel because its dimensional change during hardening is very small. However, it has a disadvantageous property of a marked tendency to increase its length in rolling direction and to shrink in other directions on hardening.[1,2] This anisotropic distortion can be caused by the anisotropy in composition, microstructure and properties. Frehser[3] attributed the anisotropy of dimensional changes to the difference in thermal expansion coefficient between the matrix and the carbide stringers. According to his explanation, during the heating-up period to the austenitizing temperature the carbides do not expand so much as the matrix, but during cooling the carbides impede the thermal contraction of the matrix in the longitudinal direction. Dilatometric analysis showed that the phase transformation had an important role in the mechanism of anisotropic distortion.[4] Recently, T. Shimizu et al. reported that dimensional anisotropy was not affected by carbon content and phase transformation, but was affected by the volume of large primary eutectic carbides.[5] In this study anisotropic behavior of SKD11 tool steel was investigated by measuring continuously the dimensional change during simulated hardening and tempering heat treatment process with high speed quenching dilatometer.

2 MATERIALS AND METHODS

A commercial forged and flat-bar rolled SKD11 tool steel has been used and its chemical compositions are shown in Table 1. Based on this composition, possible phases and amount of carbides have been calculated by using FactSage. The steel was provided as annealed at 870°C for facilitating machining. Annealed microstructure is composed of a ferrite matrix with M_7C_3 primary eutectic carbides and finely dispersed secondary carbides. Dilatometric experiments were performed using high-speed quenching dilatometer. Cylindrical dilatomery specimens, nominally 3 mm in diameter by 10 mm long, were machined in two orientations. The longitudinal direction of the specimen was oriented either in parallel to or perpendicular to rolling direction and identified as “longitudinal” and “transverse”, respectively. Specimens were heated at 0.5°C/s to austenitizing temperature and held for 60 min followed by cooling at 0.8°C/s to near room temperature and then heated up again at 0.5°C/s to tempering temperature and held for 180 min followed by cooling at 0.5°C/s to room temperature. Austenitizing temperature was 980°C, 1030°C or 1080°C, but tempering temperature was maintained at 500°C during all experiments. Different austenite temperatures were chosen in order to investigate the effect of austenitizing temperature on anisotropic dimensional change behavior. The heating and cooling rate were so selected as to be very similar to those used for hardening SKD11 tool steels in most heat treatment company.

Table 1. Chemical compositions of SKD11 tool steel used in this study [weight %]

Fe	Cr	C	Mo	V	Mn	Si
Balance	11.6	1.51	0.85	0.25	0.24	0.2

3 RESULTS AND DISCUSSION

3.1 Prediction of Equilibrium Phase

Figure 1 shows prediction of thermodynamic equilibrium phase calculated by FactSage based on chemical compositions in Table 1. At austenitizing temperature of 980°C, $M_{23}C_6$ carbides are expected to dissolve completely into austenite matrix and the amount of M_7C_3 carbides become near maximum. As the austenitizing temperature increases up to 1030°C or 1080°C, M_7C_3 carbides start to dissolve gradually into FCC matrix. Most of the M_7C_3 primary eutectic carbides are known to be formed during solidification in ingot casting.

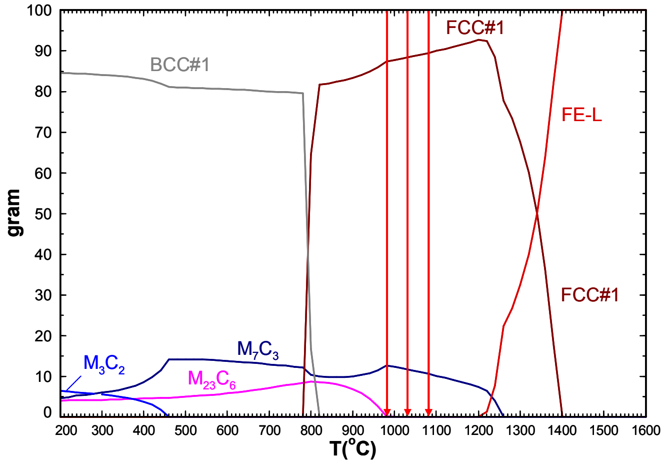

Figure 1. Thermodynamic equilibrium phase calculation by FactSage program.

3.2 Dilatometric Measurements

Figure 2 shows dilatometric results at three different austenitizing temperatures for longitudinal and transverse specimens of a SKD11 tool steel. The figures plot axial expansion versus temperature. During heating, there is a temperature where axial contraction starts near at 800°C. This temperature corresponds to BCC to FCC transformation temperature, and is in good agreement with the FactSage calculation results in Figure 1. During cooling, there exist a temperature where martensitic transformation starts, and this temperature becomes lower as the austenitizing temperature is higher.

For clear comparison, the length change difference (length change in longitudinal specimen minus length change in transverse specimen) is plotted again in Figure 3. The results show length change difference between longitudinal and transverse direction occurs not during heating but mostly during cooling, and it increases as the austenitizing temperature increases. Both banded morphology of primary M_7C_3 carbides along rolling direction and their solubility dependency on austenitizing temperature are considered to have an important effect on anisotropic dimensional change of SKD11 steel.

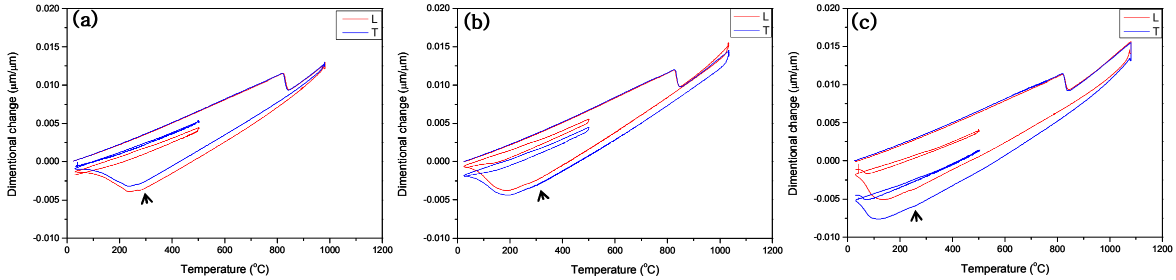

Figure 2. Dilatation curves of longitudinal and transverse specimens of a SKD11 tool steel. Austenitizing temperatures (a) 980℃, (b) 1030℃, and (c) 1080℃ with the same tempering temperature of 500℃.

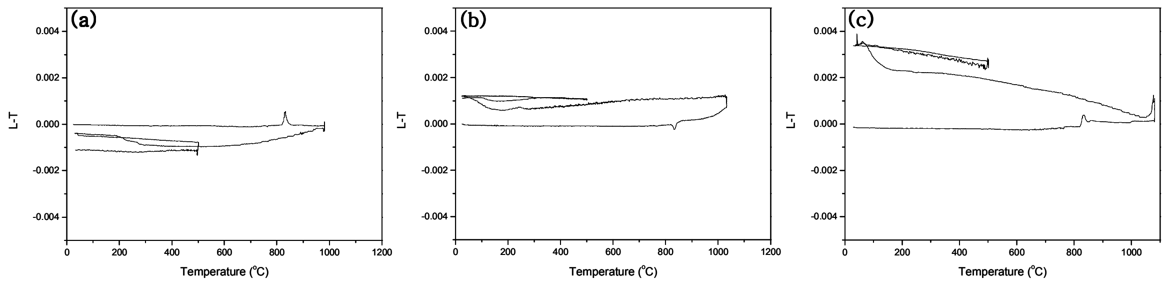

Figure 3. Length change difference between longitudinal and transverse specimens of a SKD11 tool steel (same data shown in Figure 2). Austenitizing temperatures (a) 980℃, (b) 1030℃, and (c) 1080℃ with same tempering temperature of 500℃.

4 CONCLUSIONS

Anisotropic dimensional change of forged and flat-bar rolled SKD11 tool steel during hardening and tempering heat treatment has been investigated by dilatometry. Anisotropic dimensional distortion in SKD11 occurs not during heating but mostly during cooling, and it increases with increasing austenitizing temperature for hardening. The distribution of elongated primary carbides and their solubility behavior are considered to affect anisotropic dimensional change of SKD11 tool steel during heat treatment.

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