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Measurements of Carbon Content in M-A Constituent in HAZ of High Strength Steel Welds†

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KEY WORDS: (High Strength) (Heat Affected Zone) (Simulating) (Martensite) (Austenite) (Carbon) (X Rays)

It is well known Martensite-Austenite (M-A) Constituent concentrated with carbon has harmful effect on the toughness of heat-affected zone (HAZ) of high strength steel. There has been little or no reports, however, studying the carbon concentration in M-A Constituent experimentally.

In this report, the carbon content of M-A Constituent was decided by means of X-ray diffraction on the assumption that the lattice constant of retained austenite is caused by the carbon concentration in the austenite in M-A Constituent, which is also considered to be nearly equal to that in the martensite in M-A Constituent. The chemical compositions of 60 and 80 kgf/mm^2 class high strength steels are listed in **Table 1**. Various kinds of thermal cycles for simulating HAZ were applied to the specimens machined to the shape of 13 mm in diam and 65 mm in length with high frequency induction heating apparatus. The conditions of thermal cycles were; peak temperature of 1350°C, holding time of 25 sec, several kinds of cooling time from 800 to 500°C ($\Delta t_{800-500}$) was set between virtually zero (water-quenched; W.Q) and 425 sec.

X-ray diffraction was carried out with diffractometer on the longitudinal crosssection polished electrolytically. Diffraction conditions were target of Cr, tube voltage of 40 kVp, tube current of 30 mA, and scanning speed of 1/4°/min. The 2θ value of peak measured with 99.99% Si powder. The lattice constant of austenite was determined with the peak of 220_γ locating at about 2θ of 127.5. Then, the carbon content was calculated by the equation (1) on the assumption that the lattice constant was affected by only carbon concentration because nitrogen content in base metal is fairly less than carbon content in general.

Table 1 Chemical composition of materials used

Material	Chemical composition (wt.%)									
	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V
HT60	0.13	0.25	1.21	0.016	0.006	-	0.19	0.16	0.10	0.032
HT80	0.11	0.31	0.87	0.012	<0.005	0.21	1.25	0.54	0.51	0.040

$$[\%]_A = \frac{\alpha_A - \alpha_B}{0.047} + [\%C]_B \qquad (1)$$

where, α means lattice constant, subscripts A and B represent retained austenite and base metal, 0.047 corresponds to the increment of lattice constant per 1% carbon increment$^{1)}$. Besides, the content of retained austenite was determined using 220_γ and 200_α. Moreover, the carbon content in M-A Constituent was measured with EPMA in differential mode to eliminate the superposition of CrL_α on CK_α.

Typical SEM microstructures of HT60 after the thermal cycles are shown in **Fig. 1**, where white phase is M-A Constituent and black phase is carbide. Bainite of B_{III} type was formed in (a) with $\Delta t_{800-500}$ of 12.5 sec. Mainly mixed bainite of B_I and B_{II}, and partly that of B_{III} was formed in (b) with $\Delta t_{800-500}$ of 25 sec. Under the conditions of $\Delta t_{800-500}$ larger than 100 sec, M-A Constituent was partly decomposed as seen in (c) with $\Delta t_{800-500}$ of 425 sec.

Figure 2 shows the behavior of 220_γ with increasing cooling time, and **Fig. 3** illustrates the characteristic features. In water-quenched specimen, two peaks of 220_γ occurred, and the authors considered that the peak locating at B occurred due to the retained austenite not enriched with carbon, and that another peak locating near $(M\text{-}A)_S$ occurred due to the retained austenite enriched with carbon at lath interface$^{2)}$. Therefore, α_B in Eq. (1) was determined from the peak at B. In the condition concept for water-quenching, two peaks locating $(M\text{-}A)_M$ and $(M\text{-}A)_S$ always occurred, and the intensity of the peak locating $(M\text{-}A)_M$ was higher than that at $(M\text{-}A)_S$.

Figure 4 shows the carbon concentrations in $(M\text{-}A)_M$, $(M\text{-}A)_S$ and their averaged value for HT60, where the

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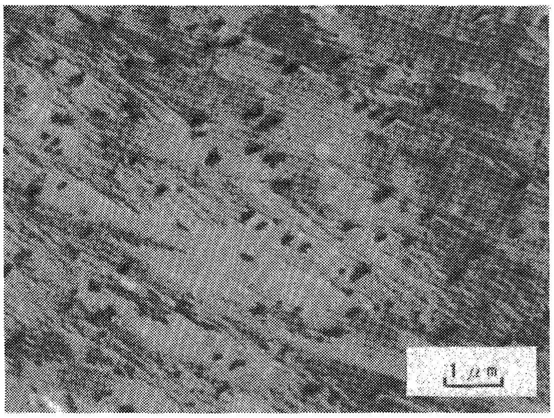
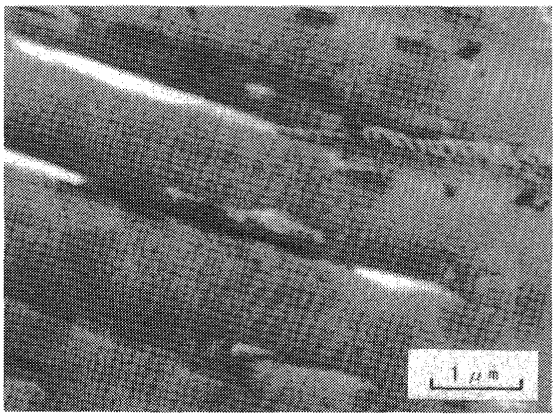
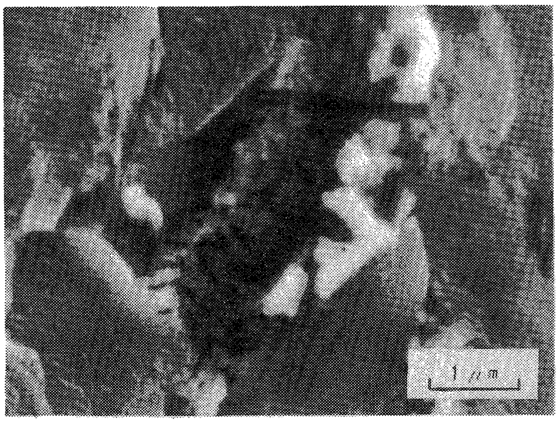


(a) $\Delta t_{800-500} = 12.5$ sec



(b) $\Delta t_{800-500} = 25$ sec



(c) $\Delta t_{800-500} = 425$ sec

Fig. 1 Typical SEM microstructures of HT60

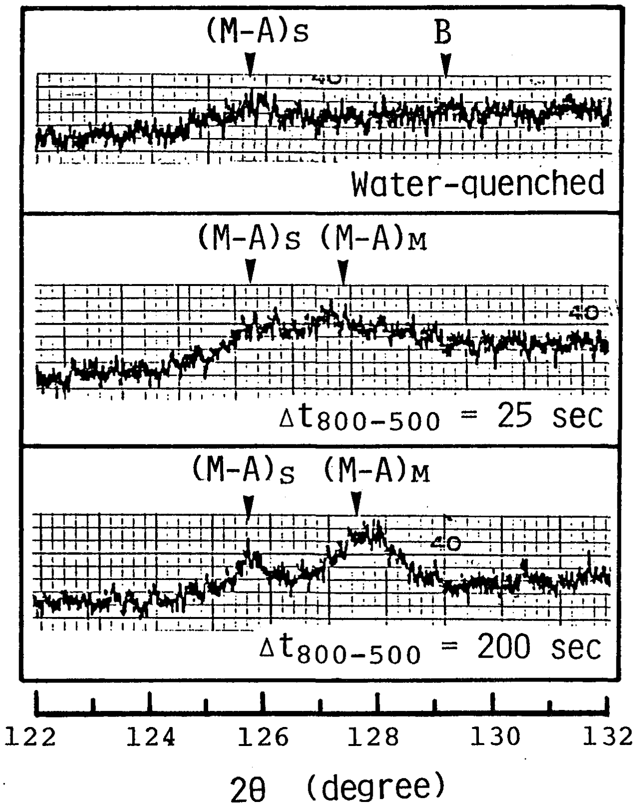


Fig. 2 Results of X-ray diffraction with various $\Delta t_{800-500}$ of HT60.

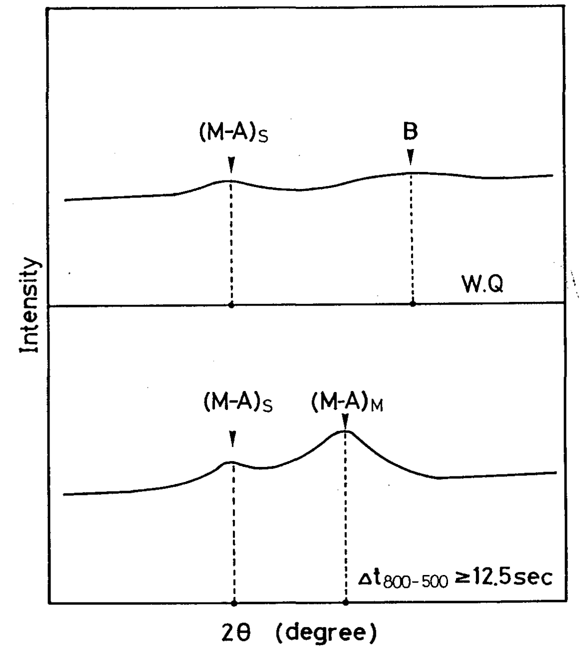


Fig. 3 Schematic representation of X-ray diffraction results.

concentrations are expressed as "I" mark because of a scattered feature of the peak at B. The concentrations in $(M\text{-}A)_M$ and $(M\text{-}A)_S$ are nearly constant at 0.6 and 1.1%, respectively, whereas the averaged concentration has a tendency to decrease with $\Delta t_{800-500}$. This decreasing tendency was also obtained in HT80, and agrees with the reports by P.G. Self[3] and H. Ikawa *et al.*[4] approximately.

Figure 5 shows the results of EPMA analysis of the matrix and M-A Constituent in HT80 with $\Delta t_{800-500}$ = 200 sec. It is possible to confirm that carbon was concentrated into M-A Constituent, but not clear whether two kinds of carbon level exist or not.

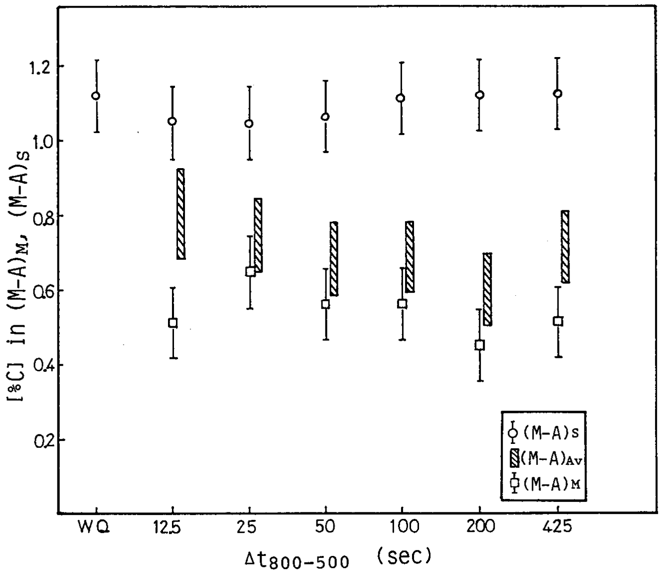


Fig. 4 Relationships between $\Delta t_{800-500}$ and [%C] in M-A Constituent.

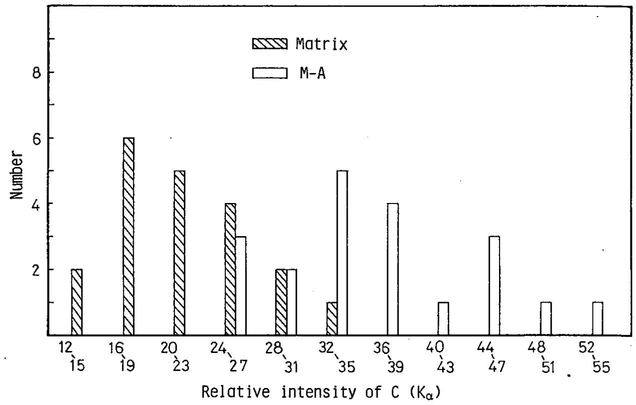


Fig. 5 Statistic analysis of carbon content by WDX (HT80, $\Delta t_{800-500}$ = 200 sec).

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