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Toughness prediction model of tempered martensitic steels

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Abstract: Toughness prediction model was made for 0.3C-1.5Mn-1.0Mo(mass%) tempered martensitic steels. The model incorporates micro structure information, FEM calculated stress distribution and fracture process criteria, and calculates a point where applied stress and material local fracture stress correspond. Following 3 stages were proposed as fracture process. Stage-I：cementite cracking. Stage-II：micro crack propagation into cementite and ferrite boundary by stress concentration caused by dislocation pile up along major axis of martensite block. Stage-III：crack propagation into first crossing 15° oriented boundary with the crack length of minor axis of martensite block. Using developed model and considering microstructure information, calculated values of toughness corresponded with measured one, and reproduced temperature dependency of toughness.

1. INTRODUCTION

Recently, high strength steel is needed to make structure large and light. Structural steel is also needed toughness to prevent fracture. To understand fracture toughness precisely, it is important to associate with micro structure and fracture process. Already, toughness prediction model has been presented for ferritic and bainitic steels[1-2]. However, such models are not developed for martensitic steels necessary for high strength steels. In this study, fracture process of tempered martensitic steel is observed and toughness prediction model is developed. Using this model, strength, grain size and cementite size effect on toughness is evaluated and experimental value of toughness is reproduced.

2. EXPERIMENT

As shown in Table 1, 0.3C-1.5Mn-1.0Mo(mass%) steel ingot was made, and rolled into 25mm thickness plate. The plate was quenched from 1250℃ after heating for 30min. to make austenite diameter uniform, then tempered at 650℃ for 40min. to vary strength and cementite size. Tensile test and Charpy impact test were conducted. 15° boundary grain size and its distribution was measured by using EBSD(Electron Back Scatter Diffraction) method. Cementite size was measured as a minor diameter. CTOD（Crack Tip Opening Displacement）test was conducted to evaluate fracture initiation toughness with 20mm thick specimen[3]. Fracture surface was observed to identify fracture initiation point and crack propagation unit.

Table 1. Chemical component. (mass%)

C	Si	Mn	P	S	Mo	t-Al	t-N	O
0.29	0.014	1.50	<0.002	0.0004	1.01	<0.002	0.0007	0.0027

3. RESULT

Fig. 1 shows micro structure. Fig. 1(a) shows optical image. Austenite grain size is almost 100-200um. Fig. 1(b) shows SEM image. Cementite was precipitated everywhere inside block and its shape was blocky. Fig. 1(c) shows EBSD IPF(Inverse Pole figure) map. Microstructure was martensite which has finely divided block and packet structure. Table 2 shows mechanical property and micro structure. In this table, grain size and cementite size are average value of top 20. In the case of calculation, size distribution is directly used.

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Fig. 2 shows effect of temperature on critical CTOD. Critical CTOD was tested twice at each temperature due to variation. Dashed line in Fig. 2 shows envelope of minimum value. Critical CTOD was increased as temperature increases.

Fig. 3 shows fracture surface observation result. Following river pattern shown in Fig. 3(a), place of fracture initiation point was identified. Fig. 3(b) shows EDS analysis result. Fracture initiation point was identified as cementite.

Fig. 4 shows EBSD IPF map across fracture initiation point. Crack propagated changing direction at block boundary, so that crack propagation unit is considered to near minor axis. Focusing on the block where fracture occurred, its major axis is equal to one of <111> direction. That means, in the worst case, stress was assumed to concentrate due to dislocation pile up along block major axis.

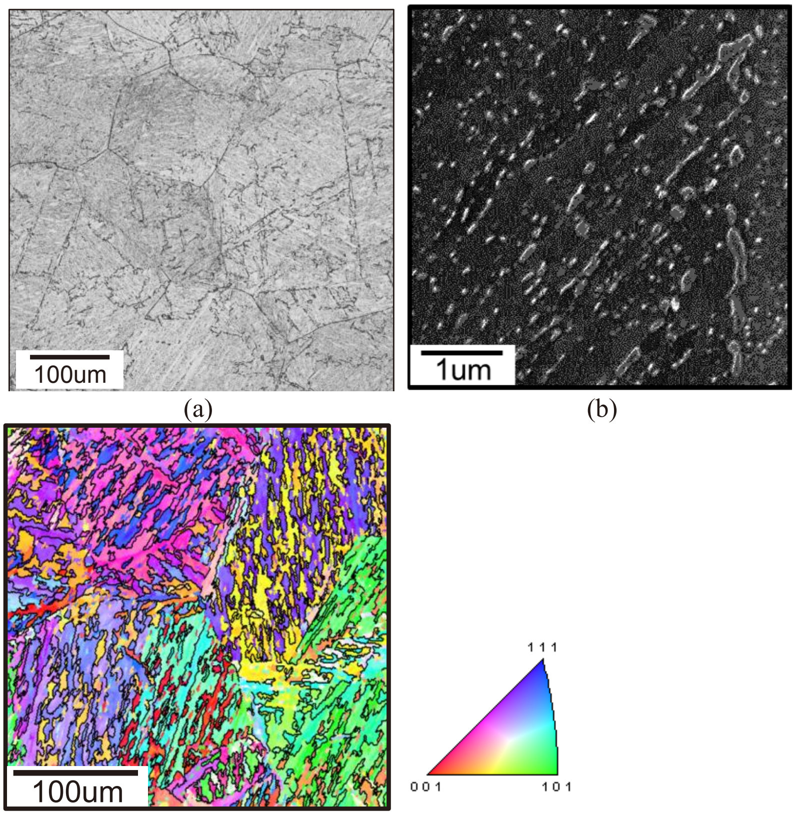


Fig. 1. Multi-scale microstructures of testing steel, (a)Optical image, (b)SEM image, (c)EBSD Inverse Pole Figure map.

Table 2. Mechanical properties and microstructure.

YS(MPa)	vTrs(℃)	EBSD 15°grain size(um) (ave. of top 20)	Cementite size(um) (ave. of top 21)
863	-29	46	0.12

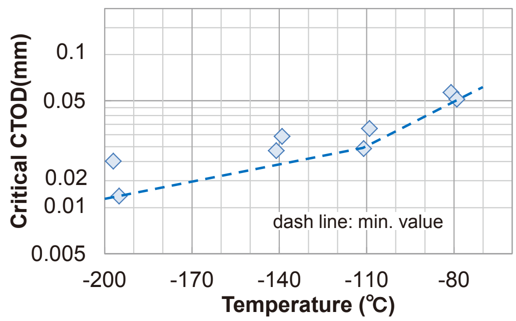
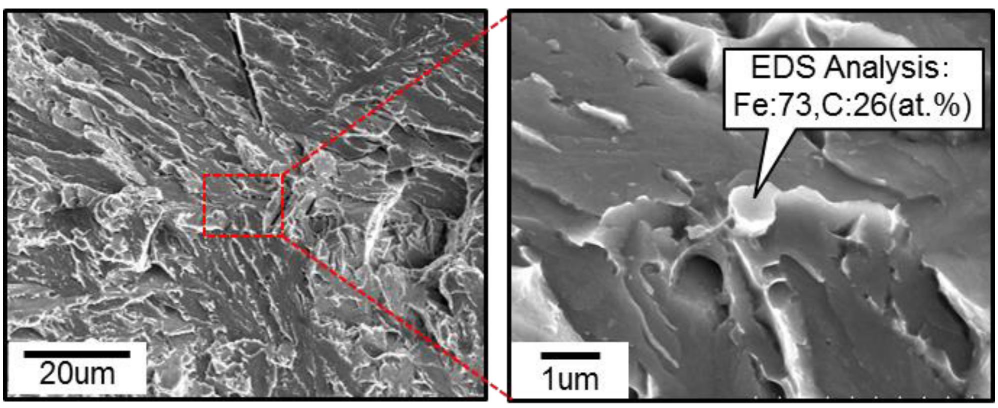


Fig. 2. Effect of temperature on critical CTOD



(a) (b)

Fig. 3. Fracture surface of CTOD test(-196℃), (a)near fracture initiation point, (b)close up of (a).

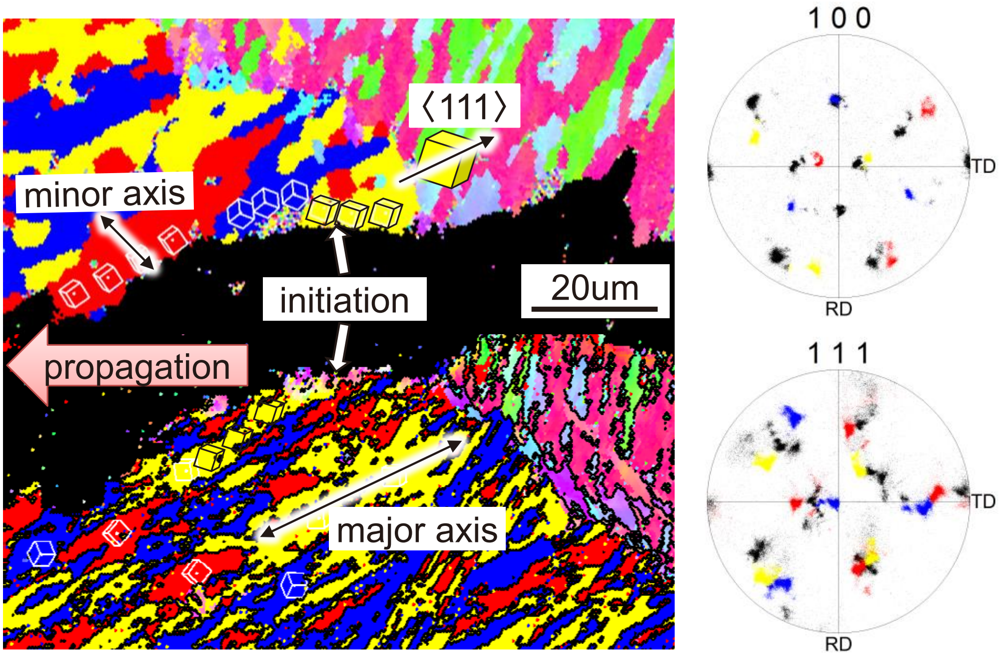


Fig. 4. EBSD IPF map across fracture initiation point.

4. MODELLING

As shown in Fig. 5, toughness prediction model incorporates micro structure information, FEM calculated stress distribution with tensile property and fracture process criteria, and calculates fracture toughness as the point applied stress and material local fracture stress correspond. From the observation results, as shown in Fig. 6, fracture process is considered as following 3 stages.

Stage-I : cementite cracking
Stage-II : micro crack propagation into cementite and ferrite boundary by stress concentration attributed to dislocation pile up
Stage-III : crack propagation into first crossing 15° oriented boundary

Fracture stress in Stage-II was defined by applying block major diameter and cementite minor size into Petch model[4], and fracture stress in Stage-III was defined by applying block minor diameter into Griffith model[5].

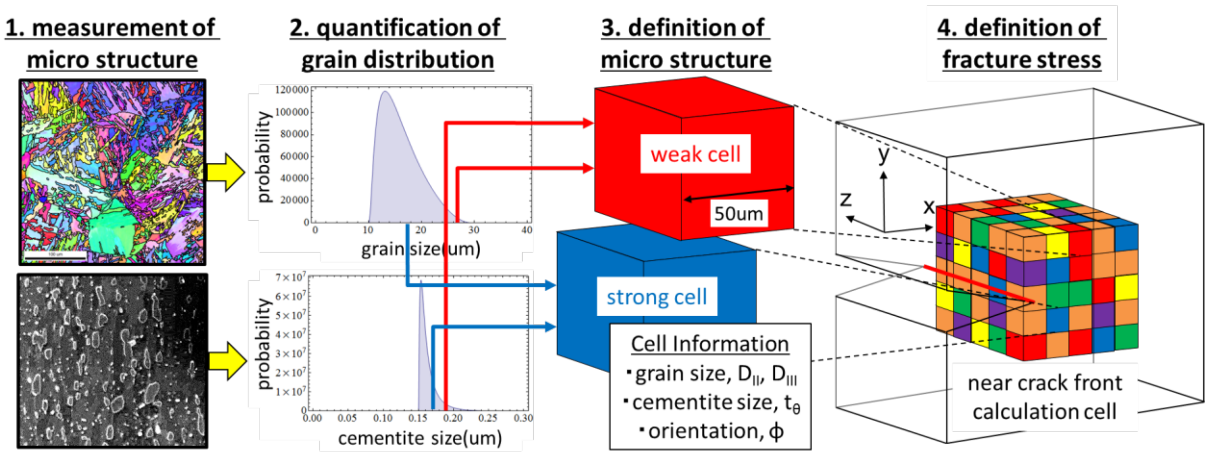


Fig. 5. Overview of toughness prediction model

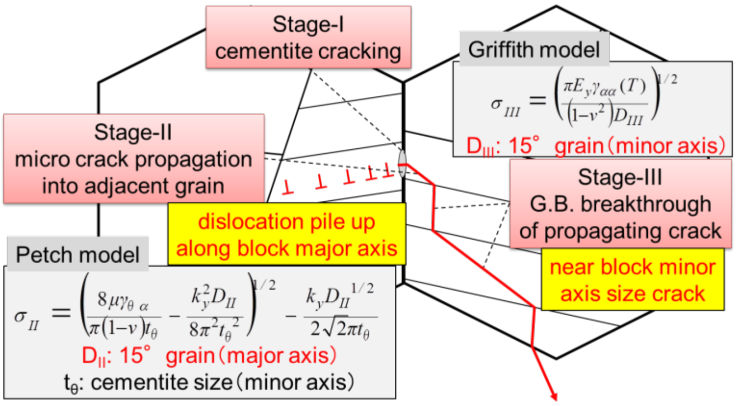


Fig. 6. Modelling of micro fracture process.

5. CALCULATION

Inputting tensile property which was converted into evaluating temperature value[6] and micro structure information, Critical CTOD was calculated. As shown in Fig. 7, Calculated value revealed temperature dependency. Moreover, as shown in Fig. 8, calculated value agreed with experimental value. The reason of a little underestimate is thought that dislocation pile up along block major axis is too severe or not considering block major axis direction toward loading direction.

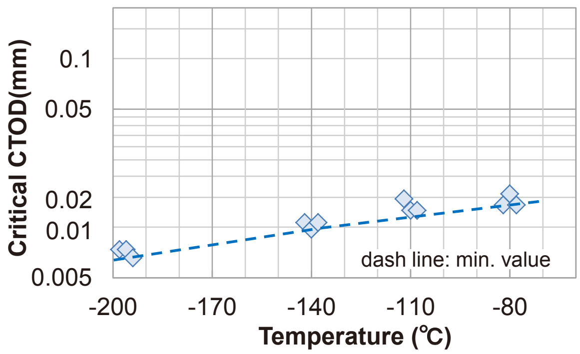


Fig. 7. Effect of temperature on critical CTOD reproduced by model calculation.

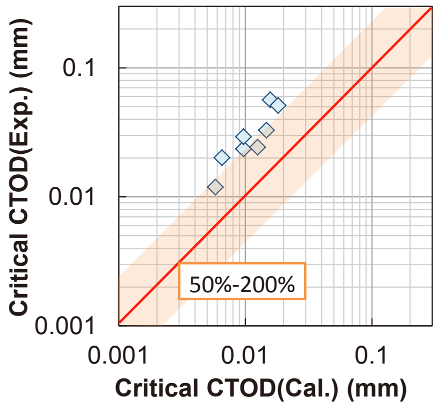


Fig. 8. Comparison of critical CTOD between experimental value and calculated value.

6. CONCLUSION

Fracture process of tempered martensitic steel was observed and toughness prediction model was developed.

・Stage-II: Stress was assumed to concentrate due to dislocation pile up along block major axis.
・Stage-III: Crack propagated in near block minor axis.

Critical CTOD was increased as temperature increased, and this trend was also reproduced by model calculation.

Further study is modeling of cementite cracking, in-situ stress distribution measurement just before fracture and evaluation of variation related to micro structure distribution.

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