# THE IN-SITU SEM OBSERVATION OF TENSILE FRACTURE PROCESSES IN LOW CARBON DUAL-PHASE STEELS

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## ABSTRACT

The really dynamic processes of tensile fracture in low carbon martensite-ferrite dual-phase steels 1010 and 1020 were observed by the in-situ technique in a scanning electron microscope. Mechanisms of initiation and propagation of microcracks are discussed. It is concluded that the dislocation pile-up model can be used for explaining the effect of the carbon content in martensite and the volume fraction of the two constituents as well as the tempering processes on the mechanism of crack initiation and propagation.

## KEYWORDS

Microscopic processes of fracture; initiation and propagation of microcracks; ferrite grain boundaries; ferrite-martensite interfaces; dislocation pile-up model; dimpled fracture; cleavage.

## INTRODUCTION

Recently, much attention has been paid to the fracture processes of martensite-ferrite dual-phase steels (Lei and others, 1982; Rashid, 1977; Speich and others, 1979). However, due to the lack of observations made directly during the deformation and fracture processes, it has been difficult to know exactly the mechanism of initiation and propagation of microcracks. The effect of heat treatment and microstructure on fracture modes seems to be very inportant from both theoretical and practical viewpoints (Kim and Thomas, 1981; Stevenson, 1977). Therefore, the aim of the present paper is to investigate the tensile fracture processes in low carbon dual-phase steels by using the in-situ technique in a scanning electron microscope and on this basis to analyze the mechanism of microcrack initiation and propagation in these steels.

## MATERIAL AND METHODS

Cold-rolled sheets 1010 and 1020 steels with standard chemical composition were used for investigation. Tensile specimens shown in Fig.1 were machined after 920 C normalizing and then heat treated according to the regimes in Table 1. The microstructures of the dual-phase steels obtained after various heat treatments were examined optically. The volume fraction of martensite ($V_M$) was determined by line interception method and the carbon content in martensite( $(\%C)_M$) was estimated according to the quenching temperature with the Fe-C phase diagram. The in-situ observations of the fracture processes were performed by using the tension stand of the electron microscope S-550 with a strain rate of approximately $1x10^{-4}s^{-1}$.

Table 1 Heat Treatment, microstructural parameters and Tensile Properties of Dual-Phase Steels

| Variant | Steel | Heat treatment | $V_M$(%) | $(\%C)_M$ | $\sigma_{0.2}$(MPa) | $\sigma_b$(MPa) | $\delta_u$(%) | $\delta_t$(%) |
|---|---|---|---|---|---|---|---|---|
| A | 1010 | 745 C Q | 10 | 0.6 | 320 | 540 | 24 | 30 |
| B | 1020 | 745 C Q | 30 | 0.6 | 455 | 740 | 14 | 17 |
| C | 1010 | 840 C Q | 30 | 0.2 | 390 | 640 | 18 | 24 |
| D | 1020 | 745 C Q +200 C T | 30 | - | 420 | 610 | 18 | 26 |

Note: Q-quench; T-temper; $\delta_u$-uniform elongation; $\delta_t$-total elongation; $\sigma_{0.2}$-0.2% proof strength; $\sigma_b$-ultimate tensile strength.

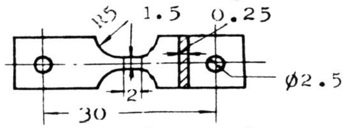


Fig.1 Tensile specimen.

## RESULTS AND DISCUSSION

### Microstructural Parameters and Tensile Properties

The microstructural parameters and tensile properties shown in Table 1 indicate that the volume fraction and carbon content in martensite phase can affect separately the tensile behavior of steels. With the same $(\%C)_M$, strength of the steels can be increased with increasing $V_M$ (comparing variants A and B) or by increasing $(\%C)_M$ (comparing C and B). This is in good agreement with the results of many investigators (Davies,1978; Speich and others,1979; Tamura and others,1973). A 200 C tempering appreciably decreases the strength of the steels with the same $V_M$ but increases the ductility parameters (comparing B and D).

### In-Situ Observations of Fracture

Fig.2 for variant A indicates that the deformation of ferrite grains is much larger than that of martensite and that the different ferrite grains deform differently due to their orienta-



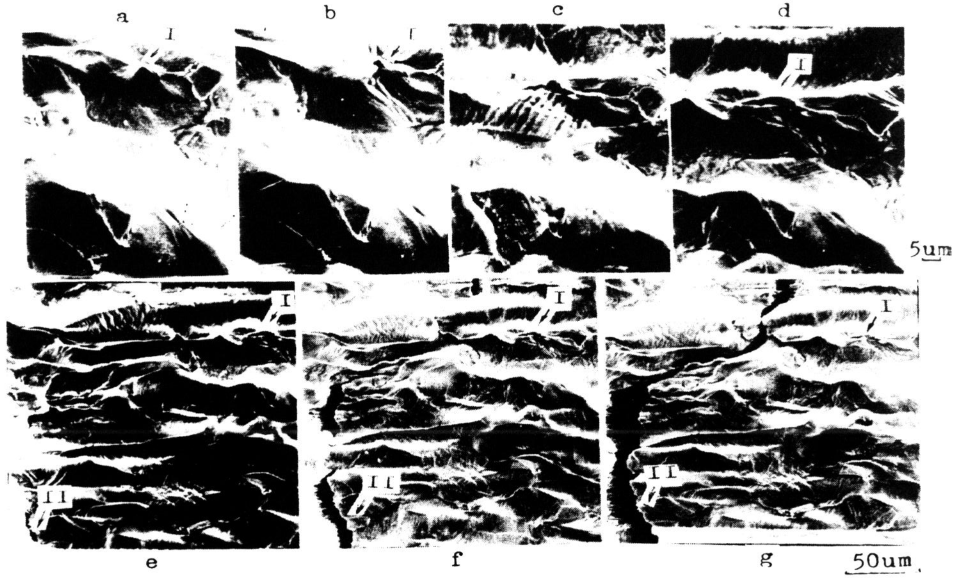


Fig.2 Initiation and propagation of microcracks in specimen of variant A ($V_M$=10%, $(\%C)_M$= 0.6) : a- $\varepsilon$=0.205; b- $\varepsilon$=0.225; c- $\varepsilon$=0.255; d- $\varepsilon$=0.260; e- $\varepsilon$=0.265; f- $\varepsilon$=0.279; g- $\varepsilon$=0.287. (Necking strain=0.24)

Crack I is parallel and crack II is perpendicular to the tensile axis.


Fig.3 Initiation and propagation of microcracks in specimen of variant B ($V_M$=30% and $(\%C)_M$ =0.6): a- $\varepsilon$=0; b- $\varepsilon$=0.150; c- $\varepsilon$=0.155; d- $\varepsilon$=0.165. (Necking strain=0.14)

tion. As a result serious strain concentrations can occur at ferrite grain boundaries (shown by arrow I, Fig.2a). After necking (Fig.2b), the strain concentration was intensified and a microcrack (arrow I, Fig.2c and d) initiates which gradually grows in the direction of tension. The microcrack II lying perpendicular to the direction of tension (Fig.2e) after initiation quickly grows on the ferrite side along highly strained grain boundary (or martensite/ferrite interface) up to fracture of the specimen (Fig.2f,g) while the crack I ceases to grow due to its unsuitable orientation. No observable deformation has been found for the martensite islands but they seriously obstruct the straining of ferrite grains causing tightly arranged slip bands in front of them. This, probably, might be one of the reasons why dual-phase steels have enhanced strain-hardening rate than commercial HSLA steels.

For variant B with higher $V_M$(=30%), as shown in Fig.3, the microcracks initiate preferentially at martensite/ferrite interfaces (Fig.3b) due to pile-up of slip bands at much less strains of ferrite grains (Fig.3c,d), which then propagate along the bands of strain concentrations, passing through the ferrite grains cleavagely or quasicleavagely (Fig.3c,d). Generally, the cracks bypass the martensite islands, but sometimes the brittle fracture of martensite islands can be observed (Fig.4).

Variant C has the same $V_M$ as B but much smaller $(\%C)_M$. Here, the morphology of martensite transforms from twinned to dislocation type and it is softer. So, although the microcracks initiate at martensite/ferrite interfaces also, they appear at much higher degrees of deformation of ferrite. The interfaces at which the microcracks initiate are those where the slip bands are seriously obstructed (Fig.5a). With increasing the applied stress the microcracks which are perpendicular to the tensile axis quickly connect together, thus forming the main crack of the specimen (Fig.6b,c). The microcracks which are parallel to the tensile axis do not propagate substantially. Although the main crack propagates essentially along the areas of strain concentrations on the ferrite side and bypasses the martensite islands, sometimes it passes through the islands (Fig.6a,b). Cracks may initiate also in narrow areas between martensite islands (Fig.6c,d).

Variant D has exactly the same $V_M$ as B but is 200 C tempered so that the strengths of both martensite and ferrite phases are unavoidably decreased. Optical and TEM examinations show that carbide partcles are precipitated in both phases (Lei and Shen, 1982) and in this case microcracks initiate preferentially at martensite/ferrite interfaces and sometimes within ferrite grains by void nucleation in forms of dimples arround carbide particles (Fig.7a). The microcracks which are essentially perpendicular to the tensile axis connect together along the directions of concentrated shear strains (Fig.7b,c), thus forming the main crack which then propagates along martensite/ferrite interface by void coalescence. In a few cases, microcracks initiated within martensite islands, but still the main crack almost always bypassed the martensite islands.

Some investigators (Baburamani and others, 1982; Marder, 1982) considered that the microcracks in dual-phase steels during tension initiate far before necking. Experimental results of the present



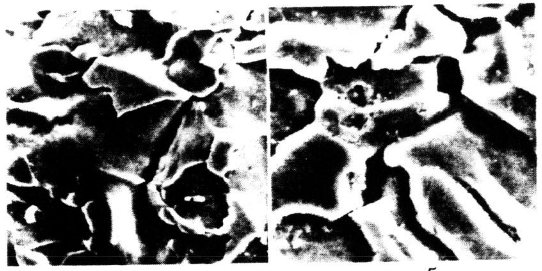


Fig.4 Cracks in specimen of variant B showing: a-cleavage in ferrite; b-brittle fracture of martensite islands.

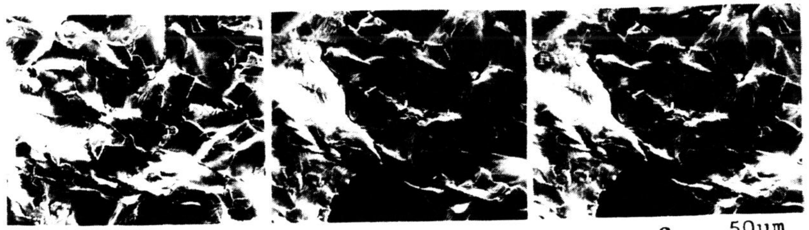


Fig.5 Initiation and propagation of microcracks in specimen of variant C ($V_M$=30%, $(\%C)_M$= 0.2): a- $\varepsilon$=0.185; b- $\varepsilon$=0.195; c- $\varepsilon$=0.210.


Fig.6 Cracks in specimen of variant C; a- $\varepsilon$=0.200; b- $\varepsilon$=0.215; c- $\varepsilon$=0.180; d- $\varepsilon$=0.190. Cracks in a and b passed through martensite islands, in c and d passed through narrow areas between islands. islands.

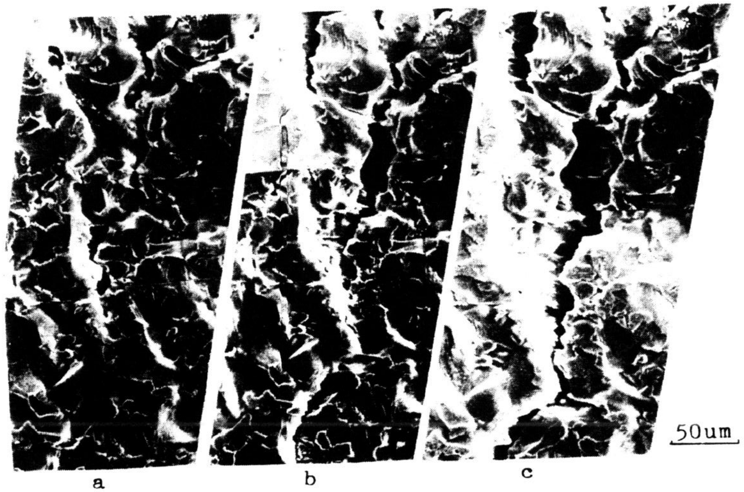


Fig.7 Initiation and propagation of microcracks in specimen of variant D ($V_M$=30%,$(\%C)_M$=0.6 and tempered at 200 C);
a- $\varepsilon$=0.205; b- $\varepsilon$=0.230; c- $\varepsilon$=0.250.

Table 2 Characteristics of Microcrack Initiation and Propagation in Dual-Phase Steels

| Variant | Initiation | | | | Propagation | |
|---|---|---|---|---|---|---|
| | Ferrite grain-boundaries | M/F interfaces | Within M | Within F | Within F | Within M |
| A | Majority | Few | No | No | By dimples | Bypassing M |
| B<br>B | Very few | Majority | Few | Few by cleavage | Dimples mixed with cleavage | Bypassing M. Few islands by cleavage |
| C | Very few | Majority | Few | No | Dimples mixed with quasicleavage | Bypassing M, few islands by dimples |
| D | Very few | Majority | Few | No | Void coalescence at M/F interfaces | Bypassing M |



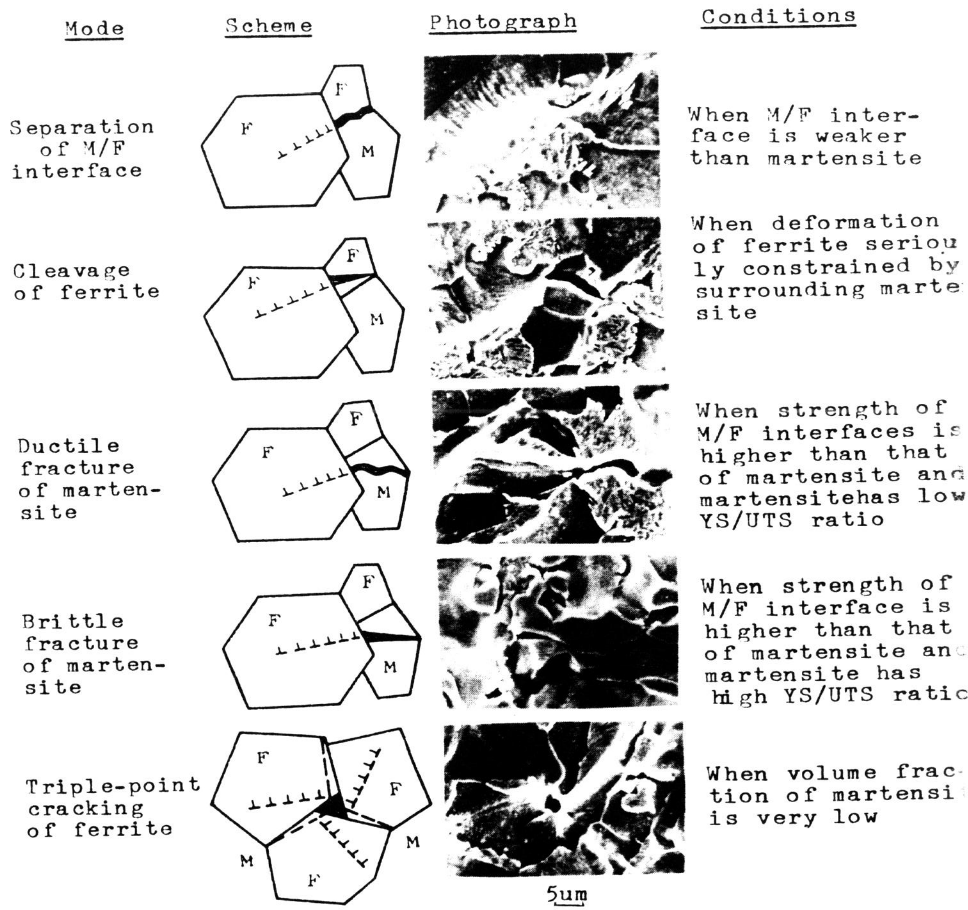


Fig.8 Modes of initiation of microcracks in dual-phase steels illustrated by dislocation pile-up mechanism.

study indicate that for variously heat treated dual-phase steels the microcracks which can propagate and connect together initiate essentially after necking, as was shown optically by Marder(1982).

## SUMMARY

Problems concerning the initiation and propagation of microcracks in dual-phase steels are rather complex. Korzekwa and others and Rashid(1977) considered that microcracks initiate only at martensite/ferrite interfaces. Szewczyk and Gurland(1982) have found that the microcracks form by dimples arround impurities. Gerbase and others(1979) reported the initiation of cracks within martensite islands. In fact, from the observations taken here by using the in-situ technique, microcracks in dual-phase steels can initiate by various modes according to their microstructural features, mainly the volume fraction and carbon content of martensite phase. Generally, there are five modes of the initiation of microcracks, namely: (a) at martensite/ferrite interface; (b) by cleavage in ferrite; (c) by dimples in martensite; (d) by cleavage in martensite and (e) at ferrite grain boundaries. Fig.8 shows schematically and on micrographs these five modes which are illustrated by dislocation pile-up model. The characteristics of initiation and propagation of microcracks in steels 1010 and 1020 are summarized in Table 2 which needs no further explanation.

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