EXPERIMENTAL STUDY ON SEPARATION FRACTURE WITH A HIGH COMPLIANCE TESTING MACHINE FOR GRADE 50 KG-CLASS HIGH STRENGTH STEEL

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ABSTRACT

The characteristics of separation generation using 50 kg-class high strength steel (JIS SM50A) were studied. Using springs in the loading system, fracture behavior under high compliance-loading was also investigated.
The results are as follows:
(1) The separation generation depended on the temperature. It occurred above -100°C and attained a maximum at roughly -50°C.
(2) Specimens thicker than 15 mm behaved as if consisting of two pieces due to the generated separations.
(3) In some instances under high compliance-loading, the separation generated beyond the maximum load induced ductile unstable fracture. No particular compliance dependence was observed.

KEYWORDS

Ductile unstable fracture; high compliance; separation; new controlled rolling steel.

INTRODUCTION

Recent progress in steel making has let to the development of controlled rolling method for the production of high strength steels of 50 kg-class (CR steels). The new CR steels have excellent toughness and weldability but poor resistance against separation formation.
On the other hand, it is undeniable that there remains the possibility of inducing ductile unstable and/or brittle unstable fracture under high compliance-loading (soft loading). Various investigations (Hutchinson, 1979; Paris, 1979; Vassilaros, 1982; Yagawa, 1982) on ductile unstable fracture have been recently carried out. However basic researches on unstable fractures of 50 kg-high strength steel are few in the literature. The present paper describes:
(1) The basic characteristics of separation,
(2) Effects of separation under high compliance-loading.

SPECIMEN AND EXPERIMENTAL PROCEDURES

Commercially available 32 mm thick 50 kg-high strength steel (Japanese Industrial Standards SM 50A) was used. Table 1 shows their chemical compositions and mechanical properties. Both soft and hard (rigid) loading tests were performed on the ASTM E813-81 specified 25 mm thick compact tension specimens. The specimens were machined from the center of the parent material in the L-T direction, and a fatigue per-cracked to 2 mm. Hard loading tests were mainly performed to investigate the characteristics of separation. In the case of soft loading tests, a coil spring (spring constant of 686~1960 kN/m) was introduced between the crosshead and the specimen in order to increase the compliance within the test system, as shown in Fig. 1. The displacement rates were 2 mm/min and 20 mm/min, for hard and soft loading tests respectively. During the test load versus load-line displacement and load versus crosshead displacement were recorded.

TABLE 1 Chemical composition and mechanical properties of plate tested, JIS SM50A.

Chemical Compositions (%)				
C	Si	Mn	P	S
0.17	0.39	1.46	0.020	0.011

Temp. °C	σ_{ys} MPa	σ_B MPa	σ_{fs} MPa
+50	412	510	461
-50	451	568	510

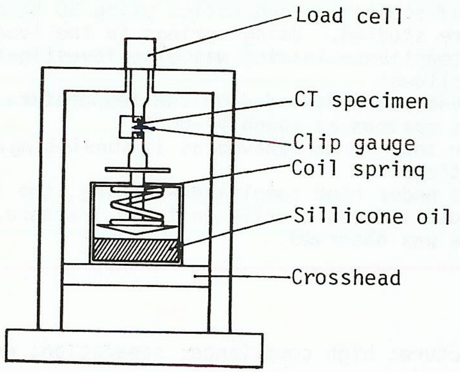


Fig. 1. Schematic illustration of ductile instability tests equipment.

RESULTS AND DISCUSSIONS

(1) The characteristics of separation generation

The temperature dependence of the separation genenation under hard loading was examined. Fig. 2 shows the ductile fractured specimen at +10 °C and -50 °C. The longest and the deepest separation occurs nearly at mid thickness. Fig. 3 shows the frequency distribution of the separation length. The hard loading tests were performed at the temperature range of -100 °C~+9 °C, where the lengths of the separations developed in the fracture surface were measured by using an optical microscope at low magnification. At +9 °C, one or two 1~5 mm-long separations developed, whereas between -25°C~-75°C, the separations increased in number and many relatively short separations were observed.

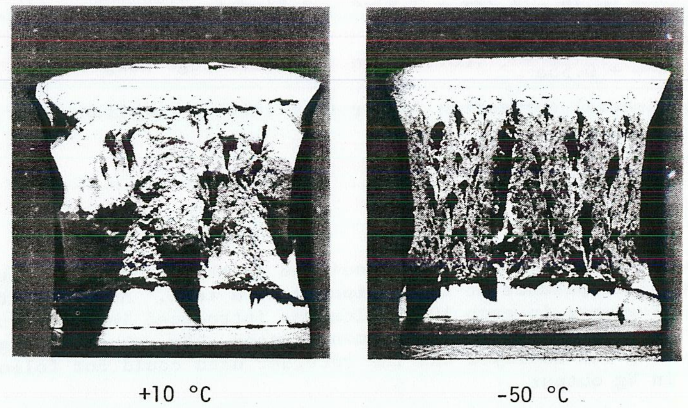


Fig. 2. Typical fracture surfaces.

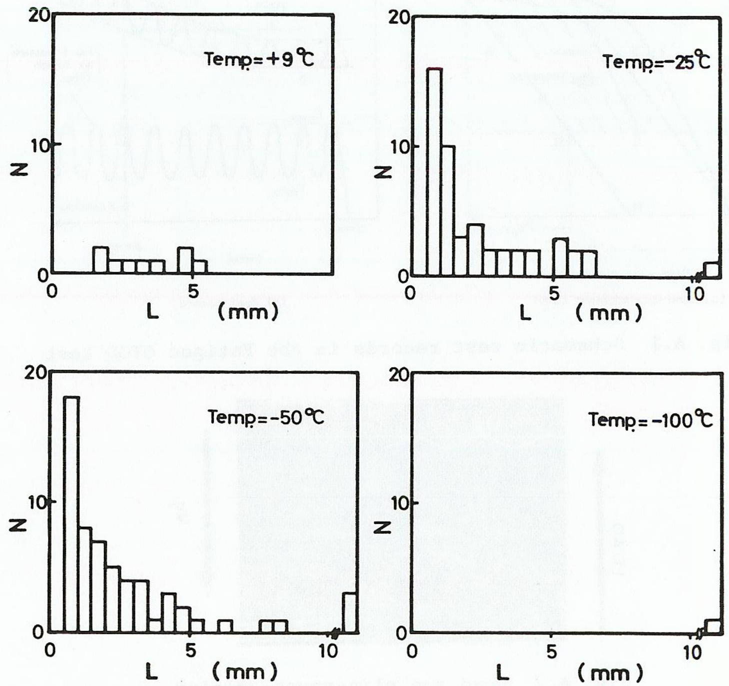


Fig. 3. Distribution of separation lengths at various temperature.

The specimens at -100℃ exhibited brittle fracture, so no separations under 10 mm-long were encountered.
The scanning electron microscopic (SEM) observations to soft loading tests (at the spring constant of 686 kN/m) revealed dimples on the ductile stable fractured sections, slightly elongated dimples and quasi-cleavage fractures on the ductile unstable fractured sections and cleavage facets on separation zones.
Separation index S.I. (Sugie, 1983)(S.I.= $\Sigma L/(B \times b)$, where L:separation length, B:specimen thickness, b:ligament) is commonly used to represent the characteristics of the separation generation. Fig. 4 gives the temperature dependence of S.I.. Similar to the increase in fracture toughness with the temperature, the S.I. increases up to a maximum at approximately -50℃, and then gradually decreases with the increasing temperature. As previously stated, specimens brittle-fractured at temperatures below -100℃.

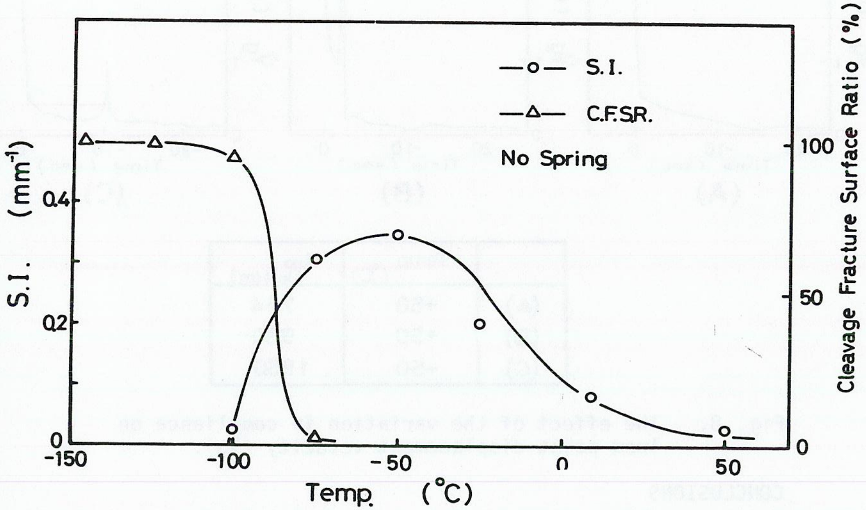


Fig. 4 Temperature dependence of separation index S.I..

The effects of the compliance on S.I. were examined under soft loading conditions. The tests were performed at temperatures of +50℃ and -50℃ with the spring constants varying from 680 to 1960 kN/m. The results are shown in Fig. 5. Values tend to somewhat increase in the higher compliances, but are nearly constant in general. It is therefore assumed that influences of compliances are negligible in the separation generation.

(2) The effect of plate thickness

The effect of specimen thickness on S.I. was examined under hard loading tests. No such long and deep separations were observable in the center of specimens below 10 mm thick. As shown in Fig. 6, the S.I. tends to increase with thickness up to 10 mm and remains relatively constant in the range of 10~15 mm, and then again re-increases beyond 15 mm.

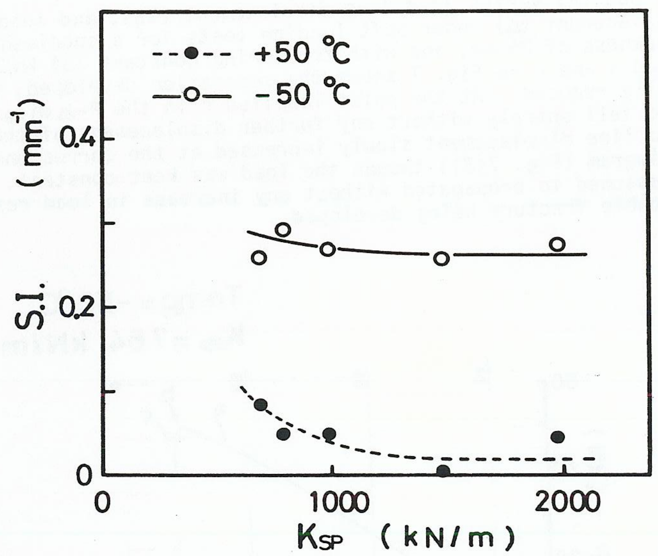


Fig. 5 Spring constant K_{sp} dependence of S.I..

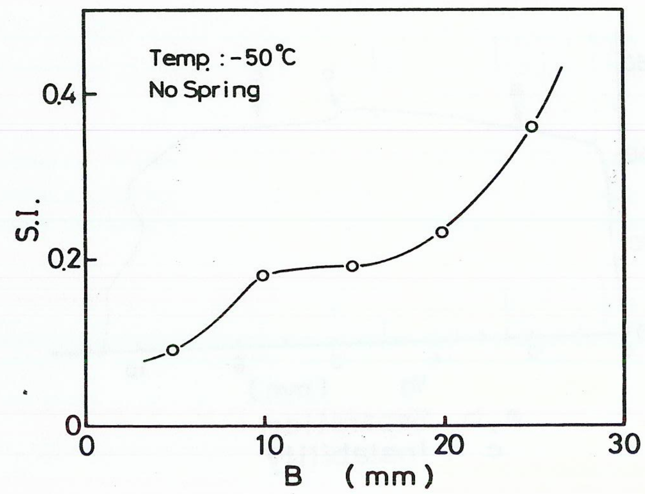


Fig. 6 Variation of S.I. with specimen tickness B.

(3) Ductile unstable fracture

Fig. 7 shows load (P) versus load line displacement (V_g), and load (P) versus crosshead displacement (Δ) under soft loading tests for a specimen temperature of -50 ℃, thickness of 25 mm, and with the spring constant 784 kN/m. The points labelled a and b in Fig. 7 shows the separation developed, where the load drastically reduced. At the point labelled c in the P-Δ diagram (Fig.7 (A)), the load fell sharply without any further displacement of the crosshead, while the load line displacement slowly increased at the corresponding section of the P-V_g diagram (Fig. 7(B)) though the load was kept constant. Therefore, the crack is assumed to propagated without any increase in load resulting in a ductile unstable fracture being developed.

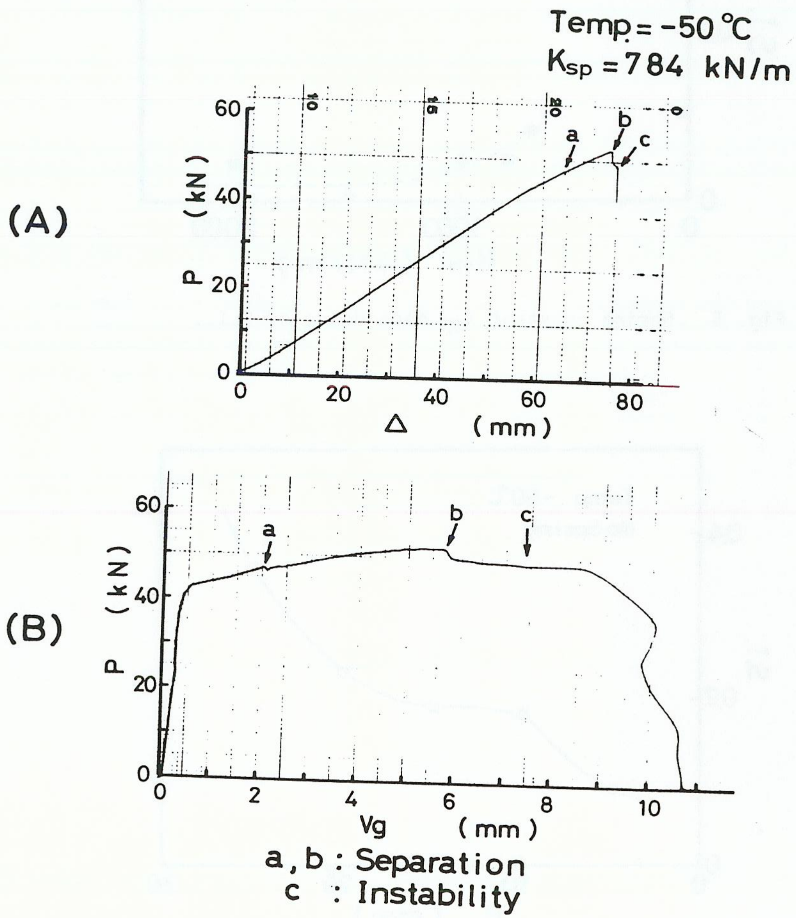
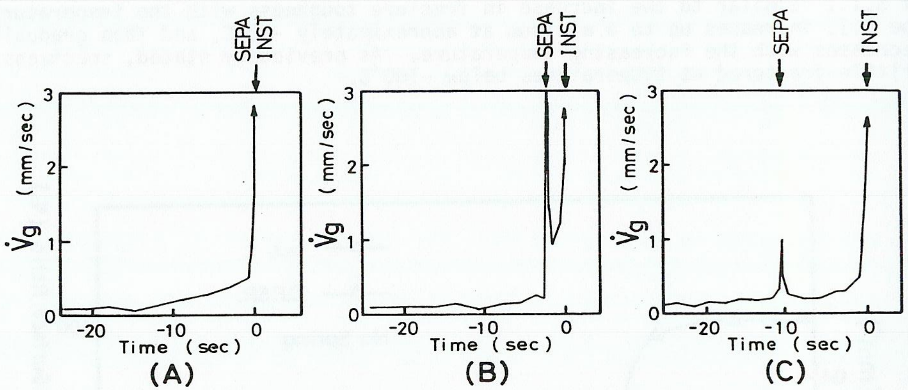


Fig. 7. Load (P) versus crosshead displacement (Δ), (A) and load (P) versus load point displacement (V_g), (B).

Fig. 8 shows the load line displacement velocity $\dot{V}_g$ just before the ductile unstable fracture occurred. The separation generated beyond the maximum load and the ductile unstable fracture concurrently occur at (A) section where the spring constant was 784 kN/m, and in (B) section where the spring constant was 980 kN/m, the ductile unstable fracture occurred before the generated separation has reached a steady state. In (C) section, the spring constant was maintained at 1960 kN/m and separation and ductile unstable fracture occurred independently.



	Temp. (℃)	Ksp (kN/m)
(A)	+50	784
(B)	+50	980
(C)	+50	1960

Fig. 8. The effect of the variation in compliance on load point displacement velocity ($\dot{V}_g$).

CONCLUSIONS

(1) The separations generated beyond the maximum load induce ductile unstable fractures under high compliance loading.
(2) The separations generation depends on temperature. It develops relatively frequently in the temperature range of -25 ℃ to -75 ℃.
(3) The separations are brittle fractures.
(4) Influences of compliance on separation generation are negligible.

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