Drop Weight Tear Test of Linepipe Materials by Using Laterally Compressed Specimens*

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Synopsis

The use of pressed notch drop weight tear test (PN-DWTT) for a highly ductile linepipe steel encounters an abnormal fracture appearance, and raises difficulty in evaluating its crack arrestability of the steel. The lateral compression DWTT (LC-DWTT) has been developed to solve this problem and comparative studies with other DWTTs were carried out.

The abnormal fracture appearance can be reduced in LC-DWTT. The 85 % shear area transition temperature in LC-DWTT was a little higher than that in PN-DWTT but lower than that in precrack DWTT (PC-DWTT). The dynamic load-displacement characteristics of LC-DWTT revealed that the crack initiation energy was reduced and the total absorbed energy was almost equal to the propagation energy of PN-DWTT. On the other hand, PC-DWTT showed the lower absorbed energy because of the plastic deformation in a specimen ligament in introducing a precrack, as compared with other DWTTs.

Key words: line pipe steel; drop weight tear test; lateral compression; fracture appearance.

I. Introduction

The drop weight tear test with pressed notch (PN-DWTT) has been adopted by API standard to define the ductile to brittle transition temperature of gas linepipe. However, a problem was encountered when applied to the recent highly tough steels such as HSLA steel or quenched and tempered steel. These steels tend to fracture at the notch root in ductile mode which is followed by brittle mode as the fracture propagates across the specimen.¹⁾

Such an abnormal fracture appearance makes it difficult to predict the arrestability of brittle fracture. As a method to prevent the occurrence of the abnormal fracture, precrack DWTT (PC-DWTT) has been proposed by the Battelle Memorial Institute.²⁾ In addition, an attempt to relate the arrestability of unstable ductile fracture with absorbed energy of PC-DWTT has been started.

But PC-DWTT has an inherent drawback. Introduction of precrack leaves a large amount of plastic deformation in the specimen, which causes the deteriorating effects in both the brittle-to-ductile transition temperature³⁾ and the absorbed energy of DWTT. The authors have already proposed a new DWT-test method named Lateral Compression DWTT (LC-DWTT).⁴⁾

This report describes the comparative study be-

tween LC-, PC- and PN-DWTT.

II. Test Procedure

1. Drop Weight Tear Test

Figure 1 shows the preparation of LC-DWTT specimen.⁴⁾ Figure 2 shows the apparatus for introducing lateral compression and the specimen for LC-DWTT. Drop weight tear test was conducted by a pendulum type impact tester, which is instrumented to obtain a dynamic load-displacement curve during DWT-testing.

In reading a fraction of shear area in a fractured specimen,[†] the API RP-5L3 method was adopted for all three types of DWTT in order to compare the

Fig. 1. Preparation of the specimen for lateral compression DWTT.

Fig. 2. Apparatus for introducing lateral compression and a specimen for testing.

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† Reference 2) has proposed that the entire fracture surface should be used in rating the shear area percent, which is in contrast to API 5L3 for the PN-DWTT.

fracture mode transition behavior of one type of DWTT with another.

2. Materials for Testing

In total, eighteen pipes shown in Table 1 were tested. They were manufactured by UOE process from controlled rolled, quenched and tempered or accelerated cooled plates. The strength grade and the toughness varied over a wide range. For pipes thicker than 20 mm, the thickness of specimen was reduced to 20 mm from both surfaces.

III. Results

Figure 3 shows the fracture appearance obtained by each notch type DWTT of highly tough material (upper shelf energy of Charpy test, $vEs_s = 26 \text{ kgf-m}$, Sample No. J). The fracture surface in PN-DWTT shows the abnormal fracture appearance, in which ductile fracture occurred just beneath the notch root and then changed to brittle mode. In both PC- and LC-DWTT, on the other hand, such ductile fracture

did not occur.

But the perfect prevention is difficult even though LC-DWTT is adopted. For extremely highly tough pipes such as Sample No. E in Table 1 ($vEs_s = 44.7 \text{ kgf-m}$), for example, the abnormal fracture appearance was observed in all types of DWTT.

Figure 4 demonstrates the effect of RLC on absorbed energy at the temperature showing 100 % shear fracture in LC-DWTT. The absorbed energy decreases with increasing RLC, and it levels off to give a constant value unique to each material at each temperature. The required RLC for obtaining a constant value of absorbed energy (LC^*) has a tendency to increase with an increase in absorbed energy of PN-DWTT. Figure 5 also shows that LC^* reaches almost constant value when the value of $PN Et / A_{PN}$ is large enough. In the case of recent linepipe steels with extremely high ductility, 25 % of RLC value is insufficient but 50 % of RLC is enough to give a constant absorbed energy in the range of materials listed in Table 1.

Figure 6 shows typical transition curves of absorbed energy and a fraction of shear area for each DWTT method. The transition curves of LC-DWTT are located between those of PC- and PN-DWTT.

Figure 7 summarizes the relation between 85 % SATT by each type of DWTT at +40°C, which shows the same tendency as in Fig. 5.

Table 1. Materials tested.

No.	Grade	Pipe Size		Pro- cess	Tensile Test		Charpy Test		PN-DWTT (full thickness)	
		Dia- meter mm	Thick- ness mm		YS kgf/mm ²	TS kgf/mm ²	50% FATT °C	Shelf Energy kgf-m	85% SATT °C	Energy at +40°C kgf-m
A	x52	610	31.8	CR ¹⁾	44.3	54.2	-82	15.4	-12	1320
B		508	22.2		47.8	57.4	-71	19.6	-9	970
L		1067	15.9		45.5	56.0	-106	7.1	-50	320
M	x60	1219	30.2	AC ²⁾	46.2	58.1	-96	40.4	—	—
O		610	22.2		45.7	59.0	-106	7.8	—	—
Q-1		1219	27.2	AC	46.3	54.5	-92	32.2	-16	2280
Q-2		"	"	QT ³⁾	49.8	56.2	-104	33.7	-19	3030
C		610	28.6	AC	48.4	57.8	-130	44.5	-53	3770
D		523	23.8	CR	49.2	59.5	-90	27.4	-37	1090
E	x65	1219	30.2	AC	53.8	58.9	-102	44.7	-17	3330
G		610	20.0	QT	49.6	63.2	-54	17.7	-17	1010
P		914	25.4	AC	51.5	61.1	-58	32.4	—	—
J		1219	38.1	QT	58.6	67.1	-30	26.0	—	—
K	x70	610	19.1	AC	52.2	65.7	-103	48.0	-23	1290
N		1420	18.7	CR	58.0	68.1	-50	8.7	+4	510
F		"	26.9		53.3	63.5	-96	9.3	-15	720
H	x80	"	20.0		60.3	69.7	-104	22.2	-26	780
I		"	18.7		62.6	74.5	-82	22.8	-9	810

1) Controlled rolled plate 2) Accelerated cooled plate
3) Quenched and tempered plate

Fig. 4. Relation between the absorbed energy of LC-DWTT and the ratio of lateral compression.

Fig. 3. Typical fracture appearances (tested at +20°C, Sample J).

Fig. 5. Change in critical value of lateral compression (LC^*) with absorbed energy of PN-DWTT.

Fig. 6. Comparison between transition curves of PN-, PC- and LC-DWTT.

Fig. 7. Relation of 85 % SATT between PN-, PC- and LC-DWTT.

IV. Discussion

1. Absorbed Energy in LC-DWTT

Figure 8 illustrates dynamic load-deflection curve during fracture at $+40^{\circ}\text{C}$ for each DWTT. Absorbed energy corresponds to the area enclosed by each curve. For convenience, the crack initiation energy in PN-DWTT was defined as the area before reaching the peak load of the curve of PN-DWTT, and also the crack propagation area as the area beyond the peak load.⁵⁾

Then the following can be seen in the curve of LC-DWTT:

(1) The energy required for crack initiation (area before reaching the peak load) decreases with an increase of RLC but does not change when the amount of RLC becomes larger than 50 %. This results correspond to Fig. 4.

(2) In crack propagation area, the load-deflection curve of PN-DWTT matches that of LC-DWTT.

In the case of PC-DWTT, the following is seen.

(1) The curve before reaching the peak load in PC-DWTT almost equals that in LC-DWTT laterally compressed up to 50 %.

(2) The curve for crack propagation area in PC-DWTT is located below those of other types of

Fig. 8. Examples of dynamic load-deflection curve for various types of DWTT.

DWTT.

The difference of curves in a propagation area is attributed to the plastic deformation of ligament caused by precracking. Figure 9 demonstrates each dynamic load-deflection curve during PN-DWTT after a tensile strain of up to 10 % (Tensile-PN-DWTT) is applied. It is seen in this figure that the propagation portion in the curve shifts downward when tensile strain is increased, which is the same trend as that of PC-DWTT. This result indicates that the absorbed energy of PC-DWTT is affected by plastic deformation of the ligament caused by precracking.

Figure 10 shows a correlation of the crack propagation energy per unit area in PN-DWTT ($P_N E_p / A_{PN}$) with total absorbed energies of PC- and LC-DWTT ($P_C E_t / A_{PC}$, $L_C E_t / A_{LC}$). Figures 8 and 10 indicate that the absorbed energy for LC-DWTT ($RLC \geq 50\%$) is almost equal to the propagation energy of PN-DWTT.

2. 85 % SATT of LC-DWTT

As shown in Fig. 7, 85 % SATT of LC-DWTT is higher than that of PN-DWTT but lower than that of PC-DWTT. The reason why 85 % SATT of LC-DWTT is higher than that of PN-DWTT seems to be a higher sensitivity to a brittle fracture of the notch in LC-DWTT. Iwasaki *et al.*¹⁾ reported that 85 % SATT lowered as the root radius of the V-notch in PN-DWTT increased. It is considered that the lateral compression makes the material in the vicinity of notch including a notch root embrittle and consequently provides the same effect as reducing the radius of the notch root.

On the other hand, the fact that the 85 % SATT of PC-DWTT is higher than that of LC-DWTT mainly comes from the embrittlement by plastic deformation in the specimen ligament during pre-cracking process. This was confirmed through the investigation which showed that 85 % SATT of Tensile-PN-DWTT rises with tensile prestrain in specimens as shown in Fig. 11.

Moreover, it is important that the rise in 85 % SATT of PC-DWTT from that of PN-DWTT (ΔT_2) is even larger than that of Tensile-PN-DWTT (tensile prestrain is 10 %) (ΔT_1), where 10 % of tensile strain almost equals a uniform elongation of this material. This fact may suggest that the sensitivity of precracked notch to brittle fracture is higher than that of pressed notch, and as a result, the 85 % SATT of PC-DWTT

Fig. 9. Effect of tensile prestrain on dynamic load-deflection curve of PN-DWTT.

Fig. 10. Relation between total absorbed energies of LC- and PC-DWTT vs. the propagation energy of PN-DWTT.

Fig. 11. Effect of tensile prestrain on absorbed energy and 85 % SATT of DWTT.

may be higher than that of 10 % Tensile-PN-DWTT. Besides, the strain beneath a precracked notch almost equals fracture strain, which is larger than the uniform elongation. So the degree of embrittlement near the notch will be stronger in PC-DWTT than in Tensile-PN-DWTT. This status will also rise the 85 % SATT of PC-DWTT.

In order to confirm the phenomenon, a more careful investigation, such as the difference of deformation mode between plastic bending and uniaxial tension and acuity of each notch, will be required.

3. Evaluation of LC-DWTT

PC-DWTT is effective to reduce abnormal fracture appearance in PN-DWTT. However, it has some problems, which are caused by plastic deformation introduced during precracking, in estimating

arrestability of both brittle fracture (85 % SATT approach) and unstable shear fracture (absorbed energy approach).

On the other hand, LC-DWTT, which can prevent the undesired abnormal fracture in a specimen, does not show such a problem as the abnormal fracture in PC-DWTT. Moreover, a process for introducing a notch is easier in LC-DWTT than in PC-DWTT which requires careful treatment in introducing a precrack.

As a result, LC-DWTT is considered to be superior to others. But the final judgment must be made through the comparison which is the most predictable for fracture arrestability of actual pipeline. So, further investigation is necessary to relate the characteristics of each DWTT with fracture behavior in a full scale burst test.

V. Conclusion

The 85 % shear area transition temperature and absorbed energy in lateral compression DWTT were studied in comparison with those of PC- and PN-DWTT and the following was concluded.

(A) Characteristics of LC-DWTT

(1) The absorbed energy decreases and 85 % SATT rises with the increase in the extent of lateral compression, but they reach a constant value unique to each material when the extent exceeds about 50 %.

(2) Both absorbed energy and 85 % SATT are between those of PN- and PC-DWTTs. In particular, the absorbed energy of LC-DWTT ($RLC \geq 50\%$) is almost equal to the propagation energy of PN-DWTT.

(B) Evaluation of LC-DWTT

(1) LC-DWTT can considerably suppress the occurrence of abnormal fracture appearance in the specimen which may occur in PN-DWTT for highly tough materials. The degree of improvement is equivalent to PC-DWTT.

(2) When compared with LC-DWTT, the PC-DWTT has a problem of strain embrittlement due to plastic bending. The LC-DWTT does not have such a problem.

As a result, LC-DWTT can eliminate the problems of both PN- and PC-DWTT, and it will be more predictable of the fracture arrestability of linepipe. Further investigation such as a full scale burst test for linepipe may be required to confirm the applicability of LC-DWTT.

REFERENCES

1) N. Iwasaki, T. Yamaguchi and T. Taira: Mech. Work. Steel Processing, XIII, AIME, New York, (1975), 294.
2) G. M. Wilkowski and R. J. Eiber: "Procedure for Conducting the Static Precrack Drop Weight Tear Test on Line Pipe", API Annual Meeting, Houston, Jan. 1979.
3) T. Taira, K. Ume, T. Ishihara and H. Ichinose: Trans. ISIJ, 20 (1980), B610.
4) T. Akiyama, Y. Hirose and N. Urabe: Trans. ISIJ, 25 (1975), 1267.
5) K. Besho, A. Inami, Y. Sumitomo and M. Tsukamoto: Tetsu-to-Hagane, 68 (1982), S1326.