EXPERIMENTAL STUDY ON THE RELATIONSHIP BETWEEN IMPACT FRACTURE PROPERTIES AND TITANIUM ADDITION FOR HSLA STEELS

Jian Fang
Technical Center, Baoshan Iron and Steel Co., Ltd., Shanghai 201900, China

ABSTRACT

Based on the determination of load variation against deflection by means of Instrumented Charpy Impact testing for characterizing the dynamic fracture properties of metals, the impact energy distribution of the High Strength Low Alloy (HSLA) steel containing Nb, Ni and Ti for pressure vessels at low temperature has been quantitatively studied. The whole fracture behavior relative to the total impact energy E_t could be subdivided into two parts, E_i and E_p. E_i is related to the matrix strength of the material in terms of the grain size and alloy addition, which is also found to be less influenced by the holding time of normalization process at 910□. Whereas, E_p of Ni-Nb-Ti HSLA steel is strongly linked to the period of holding time. Thermodynamic kinetic investigation by Transmission Electronic Microscope (TEM) reveals that it maybe the remelting and secondary precipitation of heterogeneous particles with the Face-Center-Cubic (FCC) crystal structure, simultaneously occurring in the austenite-to-ferrite transformation, dispersing onto the active sites like grain boundaries, dislocations etc., which dominates the strengthening mechanism of pinning the grain boundaries and restraining the grain growth.

1 INTRODUCTION

Impact Toughness is of importance for the evaluation of the resistance capability of structural steel against the crack initiation and rupture under high strain rate loading conditions. In general, it is of a significant evidence that the addition of low alloy element (such as V, Ti and Ni etc) and distinct heating treatment process may cause the influence on the impact toughness of High-Strength Low-Alloy (HSLA) steels.

In the paper, impact toughness property of HSLA used at the low temperature was studied by determination of the impact energy distribution, dynamic crack growth derived from the Instrumented Charpy Impact testing. In addition, Transmission Electron Microscope (TEM) was also contributed to study the behavior of secondary phase particles.

2 EXPERIMENTAL

2.1 Material preparation

Table 1: Chemical composition of the steel

□	C	Si	Mn	P	S	Al	Ni	Nb	Ti
A	0.137	0.220	1.326	0.011	<0.005	0.015	0.500	0.026	□
B	0.115	0.172	1.333	0.011	<0.005	0.017	0.494	0.022	0.013

The material investigated in the paper is a Nb-Ni-Ti containing microalloyed HSLA steel. The steel was prepared after TMCP process and normalized at 910□. Two batches of standard V-notch Charpy specimens were sampled from the middle part of the relative as-normalized steel plate. As to investigate the influence of the Titanium addition on the impact toughness, reference batches of specimens from the Nb-Ni steel without Ti were prepared in coincidence with the same treatment process as above. (Note: A-15 or A-40 means the batch A specimens normalized for 15 or 40 minutes)

2.2 Impact toughness testing

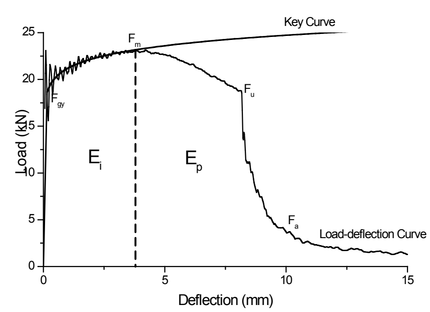

Figure 1: Curve of load-deflection recorded by instrumentation method with fitted Key Curve and the illustration of the distribution of absorbed impact energy

Fig. 1 shows a typical load-deflection curve. The meaning of the subscripts are: gy: beginning of total yielding in the ligament or, alternatively, end of the linear load range, m: maximum load value, u: beginning of unstable crack propagation, a: end of unstable crack growth. Key Curve (KC) method was adopted in the study to describe the crack extension behavior after the crack initiation [1].

3 RESULTS AND DISCUSSION

3.1 Instrumented Impact Testing

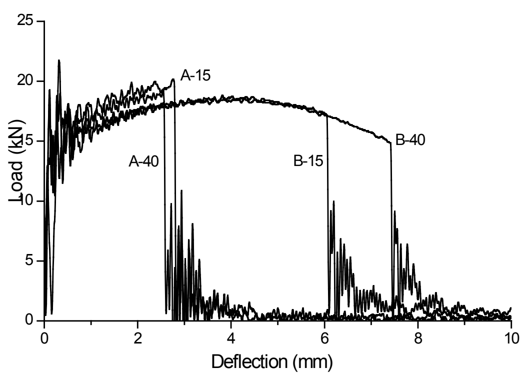

Figure 2: Curves of load against deflection for the HSLA steels after different normalization

Fig. 2 shows obvious features on the load-deflection curves for Nb-Ni and Ni-Nb-Ti steels after different normalization holding periods. For all the studied HSLA steels, steep drop of load signals occurs at the F_u point, corresponding to the starting of the unstable cracking. In comparison with batch B which shows a longer and more smooth period of stable crack propagation intervening between F_m and F_u points, Batch A is found to be a quasi cleavage fracture, implied by the unstable cracking initiating immediately after F_m point. For above, A-15 and A-40 are quite similar, as a contrast the difference between B-15 and B-40 was embodied by the length of stable crack period and the height of the interval from F_m to F_u.

In Table 2, energy distribution and the controlling parameters of n and k values for the KC, fitted corresponding to the load-deflection within the interval from F_{gy} up to F_m were also listed as well.

Table 2: Characteristic components of impact energy and parameters for Key Curve

	E_t (J)	E_i (J)	E_p (J)	n	k (N/mm)
A-15	53.8	48.7	5.1	0.110	3556.6
A-40	48.0	43.4	4.6	0.126	3539.2
B-15	110.3	68.5	41.8	0.127	3311.9
B-40	134.3	67.9	66.4	0.117	3286.4

From the Fig. 2 and Table 2, the impact toughness of Ni-Nb steel at low temperature is improved by the Ti addition. Crack extension behavior is found significantly influenced by the holding period of normalization, while it seems to be independent of E_i on the change of normalization holding period for batch B specimens.

3.2 Microstructures and Precipitates

The microstructures of batch A and B are primarily constituted by the ferrite and few pearlite. The grains size of ferrite of B is refined due to the Ti addition after TMCP process and normalization, which leads to the increase of the impact toughness listed in Table 2. TEM observation for batch B is shown in Fig. 3, which indicates that nucleation of the precipitates is confined to heterogeneity sites and the precipitation occurs in austenite or ferrite on grain boundary, dislocation, subgrain boundary during austenite to ferrite (A-F) transformation. The EDX analysis detects the abundance of Titanium, also shown in Fig. 3.

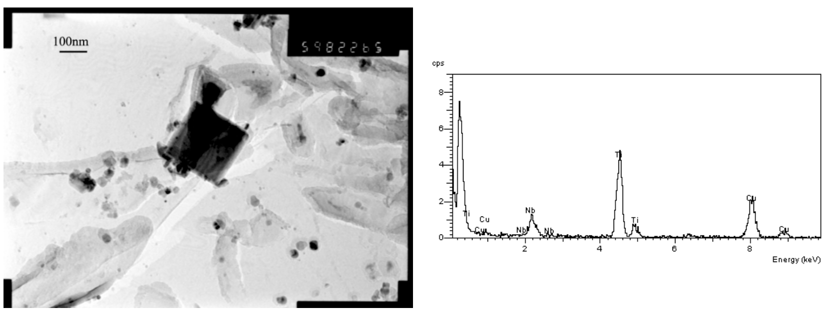

Figure 3: TEM micrography of B-40 and the EDX analysis of the chemical composition for the precipitates.

The addition of Titanium and nucleation of TiN particles provides large quantities of heterogeneity sites which transfer to the boundary of austenite and restrain its growth during A-F transformation. B-15 and B-40 experienced the same heating treatment except the different holding period, which maybe lead to the distinctive contribution of E_p to E_t.

For Batch B, on the other hand, the crack initiation energy, E_i of both specimens retains constant, independent of the normalization holding period. B-15 and B-40 were also found to have the close impact working hardening capability (n value) and impact strengthening capability (k value) by KC method, which implies the both of two specimens maybe have the same mechanical properties of matrix structure. The base yield strength (in MPa) of the steel can be estimated in terms of the grain size and alloy addition from empirical relationships such as Choquet equation [2] for plain low carbon steel.

$$\sigma_{base} = \sigma_0 + (15.4 - 30C + 6.094/(0.8 + Mn))d_\alpha^{-1/2} \qquad (1)$$

Where the concentrations are in weight percent and the ferrite grain size, d_α, is in millimeters.

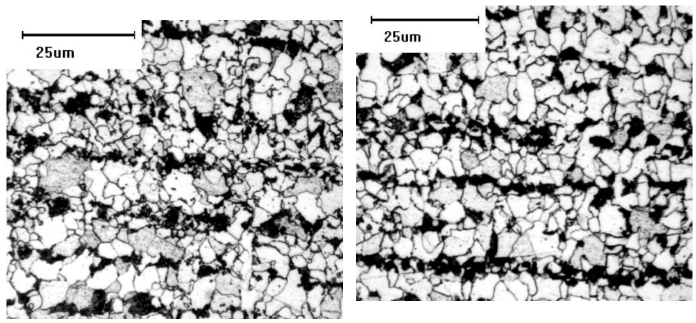

Figure 4: Metallurgical photos for B-15 and B-40 showing the distribution and grain size of ferrite, Left for B-15 and Right for B-40.

From Fig. 4, it maybe owe to the longer period of normalization treatment, which refines the arrangement homogeneity of the ferrite and removes the partial pearlite of B-40. Nevertheless, the ferrite grain size were quantified to be identical by using image analysis system, which implies the indistinguishable difference of matrix mechanical properties between two samples, considering the same chemical composition as well.

Shown in Fig. 4, adequate normalization leads to the better distribution of ferrite microstructure of B-40, compared with B-15. By the further observation in Fig. 3, except only one of the particle appears in the sight field with the dimension of 200nm, most of the dispersing particles after adequate normalization are all as small as tens of nanometers. Pinning effect interacting between particles and ferrite boundary will be enhanced by means of increasing the quantities, decreasing the dimension of dispersing particles, which are the key kinetics for strengthening the toughness under impact loading. Once the stable spreading crack meets with the strengthened boundary, the maximum stress level in front of the crack will decrease so as to bypass these nailing particles instead of the unstable propagation along the grain boundary causing fast brittle fracture.

4 CONCLUSIONS

By instrumented impact testing, E_t could be subdivided into E_i and E_p, providing abundant information about dynamic fracture properties. As regards the impact fracture energy distribution of HSLA steels studied here, E_i maintains independent of the normalization, which is believed as a matrix parameter inherently linked to the grain size and chemical composition. While, secondary phase particles containing Ti, Nb etc. are remelted and secondarily precipitated during austenization and later A-F transformation. These particles dispersing and absorbing onto the active sites dominates the strengthening and toughening mechanism, strongly improving the contribution of E_p to E_t.

REFERENCES

[1] Fang J, Ding F L, Wang C Z. Experimental Study on the Material Dynamic Fracture Properties by Instrumented Charpy Impact Test with Single Specimen Method. Journal de Physique IV France 110, 551-557 (2003).

[2] Yue S. Mathematical Modelling of Hot Rolling of Steels. The Metallurgical Society of CIM, Montreal, 34-43 (1990).