STUDIES ON THE PROCEDURE FOR THE DETERMINATION OF DUCTILE FRACTURE TOUGHNESS VALUE J_{1c} USING J-R CURVE AT LOW TEMPERATURES

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In the last few years, much research work has been conducted on the method for determining J_{1c}, by using J-integral R-curve at room temperature, as in References [1][2][3][4]. Many countries had conformed their national standard in J_{1c} testing. In Nov. 1980 China published the national standard GB2038-80 for the determination of ductile fracture toughness value J_{1c} by the J-integral techniques. Then, in Oct. 1981, a standard method of test for elastic-plastic fracture toughness J_{1c}, JSME S001-1981, was issued by the Japanese SME.And at about the same time, an American standard test for J_{1c}, ASTM E813-81, was issued by ASTM. As a result, we have had now some comparatively effective methods for determining the ductile fracture toughness value J_{1c}.

However, all the standards for J_{1c} testing mentioned above are the methods for determining J_{1c} at room temperature only. Experiments have proved that, at low temperature, if we estimate the ductile fracture toughness value J_{1c} of some structure steel, in complete accordance with these standards, we cannot get any satisfactory test results. Morever, some researchers using these standards to determine the J_{1c} value at low temperatures, cannot even get a correct relationship between the J_{1c} and temperature $t^{o}C$. Thus, it requires further work to study how to determine the J_{1c} value, by using a J-R curve at low temperatures.

From April 1980 to March 1982, our research group made a series of experiments on nearly 300 specimens of structure steel 15MnVN and 16Mn, to estimate their J_{1c} at low temperatures ($-10^{o}C$, $-46^{o}C$, $-80^{o}C$, $-113^{o}C$, $-140^{o}C$ in 1981; $15^{o}C$, $-10^{o}C$, $-20^{o}C$, $-30^{o}C$, $-40^{o}C$, $-60^{o}C$, $-80^{o}C$, from 1981 to 1982). At first, we estimated their J_{1c} values following the American standard ASTM E813-81 and the Chinese standard GB2038-80, we cannot get any satisfactory results. The relationship between their J_{1c} and temperatures $t^{o}C$ was abnormal, that is, the ductile fracture toughness J_{1c} does not decrease with the decrease of temperatures. The J_{1c} at $-113^{o}C$, $-140^{o}C$, when was converted to K_{1c}, was not equal to the K_{1c} directly determined according to the standard ASTM E399-74, by using large scale specimens. Through these experiments, we found that there are some special features in the procedures for determining J_{1c} at low temperatures by using J-integral R-curve. We made further studies in order to find the right way of determining J_{1c} at low temperatures meeting the needs of these special features. Now we present the methods which we used in our research work.

1. THE SELECTION OF VALID DATA AND THE REGRESSION OF J INTEGRAL R CURVE

In the American standard ASTM E813-81, only these data points are valid that fall within the minimum and maximum crack extension lines, if their B and $b \geq 25(J_Q/\sigma_y)$. The rules for selecting valid points for J-R curves are suitable only for the room temperature. Following these rules, we may eliminate the data points in the blunting process, to avoid their mixing up with the valid data of the crack extension process.

For the structure steel 15MnVN,L-T orientation at room temperature, the Δa

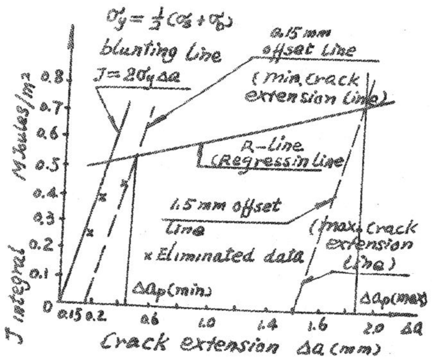

Fig. 1 Schematic of the method used to determine valid J points (standard ASTM E813-81).

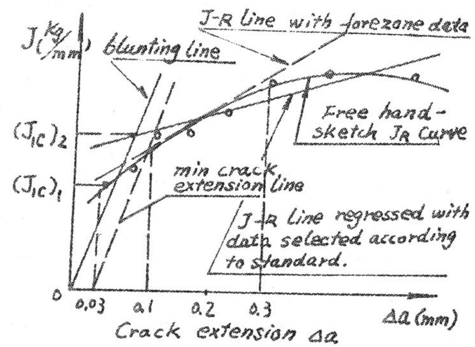

Fig. 2 Forezone data regression J-R line fits in with the handsketch J-R curve.

(named Δa_0) which corresponds to the intersection of the J-R curve and the blunting line is about 0.05--0.06mm, according to the standard ASTM E813-81. Then the Δa of the intersection point of the minimum extension line and the J-R curve, may be equal to $\Delta a = \Delta a_0 + 0.15$ mm=0.20--0.21mm. Following the Japanese standard JSME S001-1981, $\Delta a = \Delta a_0 + 0.10$mm=0.15--0.16mm; $\Delta a = \Delta a_0 + 0.03$mm=0.08--0.09mm the Chinese standard GB 2038-80. Therefore, to eliminate the data points on the left of the minimun extension line is suitable, since the Δa^* corresponding to the full crack initiation point at room temperature, is only about 0.13mm. The data points thus removed are the data points of the crack blunting process. But at low temperatures, the crack will begin to tear (or to be more exact,to be completely initiated) early than at room temperature. As for steel 15MnVN, L-T orientation at $-60^{o}C$, Δa^* is merely 0.03mm, 16Mn L-T, Δa^*=0.038mm; at $-80^{o}C$ for both of the two materials, Δa^*=0.025~0.03mm. Now as much as the data points (whose $\Delta a < \Delta a_0 + 0.15$mm) are eliminated, the data points of the stable crack propagation process will be removed, Apparently, it is not suitable at all. In reality, it eliminates the available data points of such a part on the J-R curve (regression line), which is just necessary for determining the J_{1c} value. From our research work we found that according to the American standard, a linear regression J-R line equation ($J=\alpha+\beta\Delta a$) with a much larger α and a lower β value might result. Using such a J-R curve to estimate J_{1c} of a given material will result in a higher J_{1c} value. It is clear that the J-R line regressed in accordance with the standard (ASTM E813-81), deviates more from the hand-sketch J-R curve in the forezone (Δa=0.03~0.30mm). With such a J-R line to determine J_{1c}, even with the blunting line, we always get a higher toughness value J_{1c}, as $(J_{1c})_2$. In reality $(J_{1c})_1$ is the actual J_{1c} value (as in Fig.2).

It is evident that the regression J-R line with the forezone data (Δa=0.03--0.30mm) will better coincide with the hand-sketch J-R curve in its forepart. Using such a regression J-R line, on its forepart we can easily estimate the real J_{1c} of a material. Since at different low temperatures, the crack extension of full crack initiation Δa^*(as shown in Fig.3) will decrease with the temperature decreasing.Thus for different temperatures, the method of valid data points' region selection is slightly different (For more details, see Reference [6]).Briefly these rules are as follow:

1. The selection of valid data points for J-R line regression at room

temperature has to be done completely according to the Chinese standard GB 2038-80.

2. At $-10^{\circ}C \sim -20^{\circ}C$, all the data points whose Δa correspond to $0.05 \sim 0.50$mm should be adopted as valid points for regression.
3. At $-30^{\circ}C$ and below, forezone data ($\Delta a=0.03 \sim 0.30$mm) should be taken as valid data for regression, and this part of the J-R line should be used as the main part of the J-R curve for estimating J_{1c}.

II. USING Δa^* INSTEAD OF THE INTERSECTION POINT OF THE BLUNTING LINE AND THE J-R LINE

The equations of the blunting line $J=2\sigma_y \Delta a$[7] ($\sigma_y=\frac{1}{2}(\sigma_s+\sigma_b)$) or $J=1.5(\sigma_s+\sigma_b)\Delta a$ ect,are all the approximate empirical equations at room temperature, being invalid at low temperatures. In general, crack extension Δa_0 corresponding to the intersection point of the blunting line and the J-R curve, is about $0.05 \sim 0.06$mm, whereas at low temperatures, for the steel 15MnVN, the Δa^* ($\Delta a^* < \Delta a_0$ always) is merely 0.04mm at $-40^{\circ}C$. Therefore, we have to find another method to determine the Δa corresponding to the crack full initiation (e.i.Δa^*), the Δa_0 can never be used as Δa^* to determine J_{1c} with the J-R line. For this reason, in order to determine the Δa^* more accurately, we used ultrasonic techniques and refatigue method to monitor the crack initiation, and measured the stretch zone width (SZW) and Δa^* microscopically, (some pieces were analysed by scanning electron microscope (SEM), thus making it possible to measure the SZW and Δa^* more accurately). Then, with these Δa^* we determined the corresponding J_{1c} values we needed on the J-R lines. The relationships between Δa^* and $t^{\circ}C$ for stucture steel 15MnVN and 16Mn are shown in Fig.3.

III. USING Δa^* TO DETERMINE THE J_{1c} VALUE WITH THE J-R REGRESSION LINE

By using the procedure described in paragraph 1, we can get the J-R regression line at low temperatures. Then plot a vertical line from the Δa^* on the Δa axis of the J_Q vs Δa curve, this vertical line intersects with the J-R line; and then the value J_Q of the intersection point gives the required J_{1c} value (if other criteria for validation of J_Q as J_{1c} are all fulfilled.).

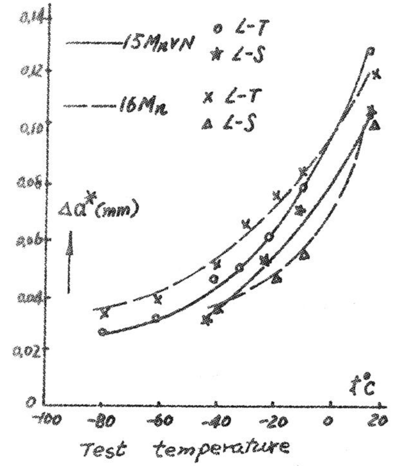

Fig.3 The crack extension Δa^* vs test temperature $t^{\circ}C$.

With the procedure described above, we determined the relation curve between the toughness value J_{1c} and tests temperatures, as shown in Fig.4. In this test, the ductile fracture toughness value J_{1c} at $-113^{\circ}C$, $-140^{\circ}C$, when it is converted to K_{1c}, agress with the K_{1c} directly determined with the large scale specimens according to the standard ASTM E399-74 or YB977-78 (Chinese standard) within the engineering error.

The J_{1c} value that we get are very close to the test results which are determined by the Iron and Steel Research Institute, using another method. Finally, with the same procedure, the J_{1c} vs $t^{\circ}C$ (at low temperatures of the two steels 15MnVN in L-T and L-S orientations) and 16Mn (L-t, L-S), with a plate thickness of 32mm, were determined, as shown in Fig.5. All these results can be valid within the engineering error.

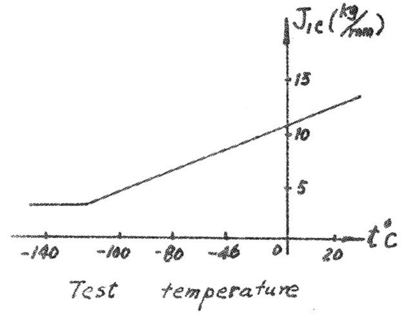

Fig.4 J_{1c} vs temp. $t^{\circ}C$ of 15MnVN (56mm steel plate).

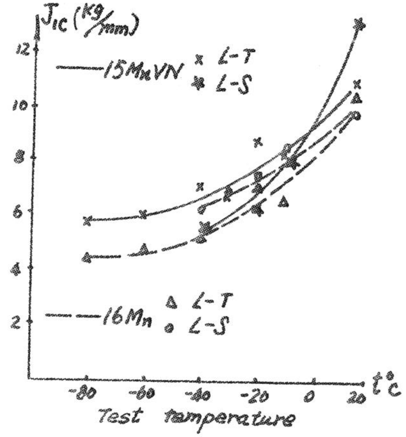

Fig.5 J_{1c} vs temp. $t^{\circ}C$ of 15MnVN and 16Mn (32mm plate).

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