INVESTIGATION ON CRACK PROPAGATING CHARACTERISTIC OF WELDED JOINTS

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ABSTRACT

In order to study the effect of weldmatching on the crack propagating behaviour the comparative DT tests have been done on the butt joints of A131 and A537 steels welded with the same kind of the electrode LB52NS. From test results it is apparent that there was no significant difference in DTE (Dynamic Tear Energy) at low temperature close to NDT for the two kinds of welded joints, however at higher temperatures, the beneficial effect of weldmatching in higher digree on the crack propagating properties of welded joints was found. From the statistics analysis it has been shown that either the DTE, or the Sa% conforms with normal distributions. Based upon Green Integration a new method for calculating Sa% was proposed also.

KEYWORDS

Propagating behaviour, weldmatching, normal distribution, fracture surface, dynamic tear energy.

INTRODUCTION

As the brittle fracture of welded structures consists of two steps: fracture initiation and fracture propagation, two alternative philosophies which can be used are to prevent fracture initiation and to prevent continued fracture propagation based upon the available results of different tests.

One of the most widely used tests determining the arresting properties of welded structures is Dynamic Tear Test, which was proposed by U.S. NAVY Institution. The test specimen and testing procedures are standardized as described in ASTM E604 and in GB5482 "Standard Test Method for Dynamic Tear Testing of Metallic Materials" in China.

In 1987 at Tianjin University the vertical drop weight machine with the new method for DTE measurement was installed. After this the Dynamic Tear Test was used for evaluation of the resistance to fracture of several steels including the welds. At the present work the new test results related to practical application are described and discussed in detail.

Table 1 The regressed results of testing data

specimen material	regression model	regression equation	N	R	$R_{0.01}$	S	F	$F_{0.01}$	R^2
A131 steel welded joint	(1)	$E=3000[1-exp(T/280)^{16.32})]$	12	0.914	0.708	6.343	50.61	10.0	0.765
	(2)	$E=1530+1470tanh[T-268/13.8]$	12	0.882	0.708	616.8	34.88	10.0	0.761
	(1)	$Sa\%=101\{1-exp[-(T/271.7)^{16.8}]\}$	11	0.945	0.735	3.922	74.7	10.6	0.851
	(2)	$Sa\%=51+50tanh[T-261.2/16]$	11	0.940	0.735	20.37	68.77	10.6	0.721
A537 steel welded joint	(1)	$E=2210\{1-exp[-(T/301.8)^{8.2}]\}$	22	0.905	0.537	8.468	90.54	8.1	0.686
	(2)	$E=1135+1075tanh[T-285.6/28.4]$	22	0.887	0.537	463.1	66.69	8.1	0.625
	(1)	$Sa\%=101\{1-exp[-(T/285.2)^{9.7}]\}$	23	0.937	0.526	6.362	152.0	8.02	0.872
	(2)	$Sa\%=51+50tanh[T-270.7/28.6]$	23	0.939	0.526	13.48	156.4	8.02	0.840

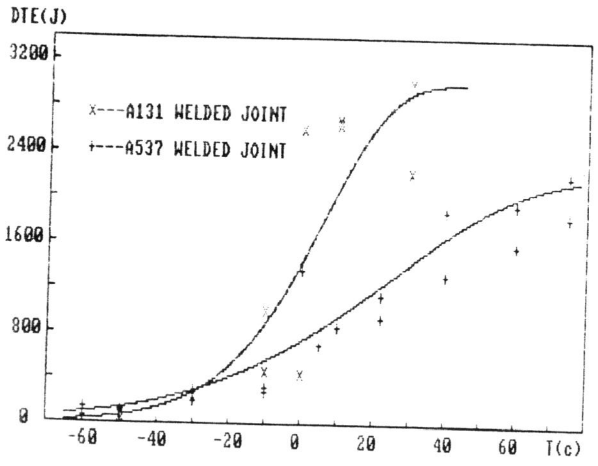

Fig.1 DTE−T curves for two kinds of welded joints tested.

CURVE FITTING AND THE EFFECT OF WELDMATCHING IN YIELD STRENGTH ON THE PROPAGATING PROPERTIES

Curve Fitting In order to plot the curve of DTE against T and the curve of Sa% aginst T more correctly, it is necessary to regress the test data. At the present study, first the A131 and A537 steels were welded with the same kind of electrode LB52NS resp., then in accordance with GB5482−85 the DT test specimens for the two kinds of welded joints with different ratio of weldmatching in yield strength were prepared and tested at different temperatures. During testing the DTE and Sa% obtained at different temperatures were measured according to the method proposed above and in reference [2] (Huo Lixing et al, 1990). After this the data for DTE−T and Sa%−T are regressed based on the two most popular models respectively.

The two models used for DTE−T are:

$$DTE=E_0[1-exp(-T/T^*)^b] \quad (1)$$

$$DTE=A+Btanh(T-T_0/C) \quad (2)$$

where T: the testing temperature;

T^*: the characteristic temperature, at which the DTE obtained is 63.2% of the upper shelf energy;

E_0: the DTE obtained at the temperature corresponding to the upper shelf.

b: constant, which indicates the degree of DTE changing with temperature.

A: the half of the sum of the upper shelf energy and lower shelf energy.

B: the half of the difference between the upper shelf energy and lower shelf energy.

C: constant, which indicates the degree of DTE changing with testing temperature.

T_0: the temperature, at which the DTE is 50% of the difference between the upper shelf energy and lower shelf energy.

The regressed results are summarized in Table 1

As R^2(correlating exponent) for model 1 are larger than that for model 2, and s(standard deviation) for model 1 are much smaller than that for model 2, it is clear that more accurate results can be obtained by using model 1 to regress.

The Effect of Weldmatching on the Crack Arresting Properties In the weling design one of the most important task which the designer must pay attention to is to choose electrode from strength point of view. The beneficial effect of overmatching of weld metals on crack initiation properties of welded joints was found based upon General Yielding Griterion by means of the wide plate test and Niblink test respectively under static and dynamic loading (Zhang Yufeng et al, 1988). In this paper in order to study the effect of weldmatching on crack arresting properties of welded structures after the comparative test have been done on the butt joints of A131 and A537 steels welded with the same kind of electrode LB52NS, the test results was analysed. From Fig.1 it can be seen that:

For the two kinds of welded joints no significant differences in the temperature T_L corresponding to the lower shelf of the DTE−T curve and DTE at this temperature were found. This means that ratio of weldmatching haven't notable effect on the crack arresting properties of welded joints at low temperature closed to NDT. It seems to be that in a brittle fracture, little or no prior deformation was occurred, so that the effect of the parent metals on the absorbed energy before fracture was negligible, and DTE at fracture was determined by the properties of weld metal alone. Since in our case the two kinds of welded joints were welded with the same kind of electrode, so that the same fracture energy, or DTE was obtained. In other words, the effect of weldmaching on crack propagating properties at low temperature will be nullified.

Tab.2 The results of curve fitting fo DTE and Sa% for A537 steel welded joints

The probability density function	Index	Parameter in P.D.F	Kormoglov method		correlating factor		Correlating exponent
			D_{31}	$D_{31}(0.05)$	R	$R_{0.01}$	R^2
Normal distribution $f(x) = 1/\sqrt{2\pi}\cdot\sigma\cdot exp[-(x-u)^2/2\sigma^2]$	DTE	$\hat{u}=1525.69$ $\hat{\sigma}=638.96$	0.468	0.895	0.985	0.456	0.978
	Sa%	$\hat{u}=55.54$ $\hat{\sigma}=16.49$	0.376	0.895	0.955	0.456	0.903
Log-normal distribution $f(x)=\begin{cases}1/\sqrt{2\pi}\cdot\sigma_x\cdot exp[-1/2\sigma^2\cdot(lnx-u)^2] & for\ x>0\\ 0 & for\ x=0\end{cases}$	DTE	$\hat{u}=7.23$ $\hat{\sigma}=0.495$	0.55	0.895	0.955	0.456	0.956
	Sa%	$\hat{u}=3.97$ $\hat{\sigma}=0.34$	0.89	0.895	0.927	0.456	0.828
Weibull distribution wifh three parameters $f(x)=\begin{cases}1-exp[-(x-c/B)^A] & for\ x\geq c\\ 0 & for\ x<c\end{cases}$	DTE	$\hat{A}=2.45$ $\hat{B}=1736.47$ $\hat{C}=0.25$	0.12	0.154	0.985	0.456	0.977
	Sa%	$\hat{A}=3.48$ $\hat{B}=62.13$ $\hat{C}=0.006$	0.103	0.154	0.96	0.456	0.898

The difference in characteristic temperature T_m corresponding to the center of the DTE–T curves between the two kinds of welded joints was 14.3℃, i.e., the T_m for A131 steel welded joints was −0.2℃, for A537 steel welded joint was +14.1℃. On the other hand, the difference in the temperature T_u corresponding to the upper shelf between the two kinds of welded joints was 39℃. i.e. the T_u for A131 steel welded joint was 25.7℃, for A537 joint was 64.8℃. Meantime the DTE at T_m for A131 steel welded joint was 380J higher than that for A537 steel welded joint, and DTE at T_u for A131 steel welded joint was 790J higher than that for A537 steel welded joint.

At high temperature a ductile fracture in which considerable deformation occurs before the pieces separate, is determined by resistance to frature of welded metal and parent metal together. This means that the parent metal can play an important role in determining the absorbed energy before fracture, and thus overmatching weld deposits will receive protection from the plastic strain of the

parent metal. In our case since the yield stress of A131 steel is lower than that of A537 steel, it will be easier for the A131 steel specimen to reach the yield strength of the parent metal and as well as to develop plastic deformation. From this point of view it is necessary to supply more impact energy to fracture A131 steel welded joint specimen, and it is thus attractive to ensure weld metal yield strength overmatching in a higher degree.

Tab.3 The results of curve fitting of DTE and Sa% for A 131 steel welded joints

The probability density function	Index	Parameter in P.D.F	Kormoglov method		correlating factor		Correlating exponent
			D_{31}	$D_{31}(0.05)$	R	$R_{0.01}$	R^2
Normal distribution $f(x) = 1/\sqrt{2\pi}\cdot\sigma\cdot exp[-(x-u)^2/2\sigma^2]$	DTE	$\hat{u}=1181.69$ $\hat{\sigma}=430.18$	0.58	0.895	0.985	0.684	0.980
	Sa%	$\hat{u}=53.77$ $\hat{\sigma}=11.38$	0.61	0.895	0.984	0.684	0.969
Log-normal distribution $f(x)=\begin{cases}1/\sqrt{2\pi}\cdot\sigma_x\cdot exp[-1/2\sigma^2\cdot(lnx-u)^2] & for\ x>0\\ 0 & for\ x=0\end{cases}$	DTE	$\hat{u}=7.01$ $\hat{\sigma}=0.39$	0.72	0.895	0.982	0.684	0.967
	Sa%	$\hat{u}=3.96$ $\hat{\sigma}=0.226$	0.83	0.895	0.966	0.684	0.938
Weibull distribution wifh three parameters $f(x)=\begin{cases}1-exp[-(x-c/B)^A] & for\ x\geq c\\ 0 & for\ x<c\end{cases}$	DTE	$\hat{A}=2.76$ $\hat{B}=1198.37$ $\hat{C}=115.90$	0.13	0.234	0.992	0.684	0.979
	Sa%	$\hat{A}=5.32$ $\hat{B}=57.18$ $\hat{C}=1.1$	0.11	0.234	0.984	0.684	0.965

PROBABILITY NATURES FOR DTE AND Sa% AT CHARACTERISTIC TEMPERATURE T_m

For DT testing steels and steel weldments exhibit a large scatter in arresting properties in the middle region of DTE–T or Sa% –T curve which are described in some references. Unfortunately, DTE or Sa% in this region are most useful parameters for designer, which are in most cases reliable quantitative evaluations of arresting properties related to the in–service performances of the material or weld metal used for welded structures. It may seem necessary to perform more work on this subject.

Based upon the available testing data (for A131 steel there are 13 specimens at 0℃, for A537 steel there are 31 specimens at 15℃) in the Dynamic Tear Test, the probability natures for DTE and

Sa% of the two kinds of steels welded with LB52NS electrode were analysed by means of statistical treatment. From testing results, curve fitting and test of goodness of fit, which are presented in Tab.2 and Tab.3 and visualized in Fig.2, it is clear that the probability density functions of DTE and Sa% for the two kinds of welded joints at the characteristic temperature $T_m$can be expressed by normal distributions.

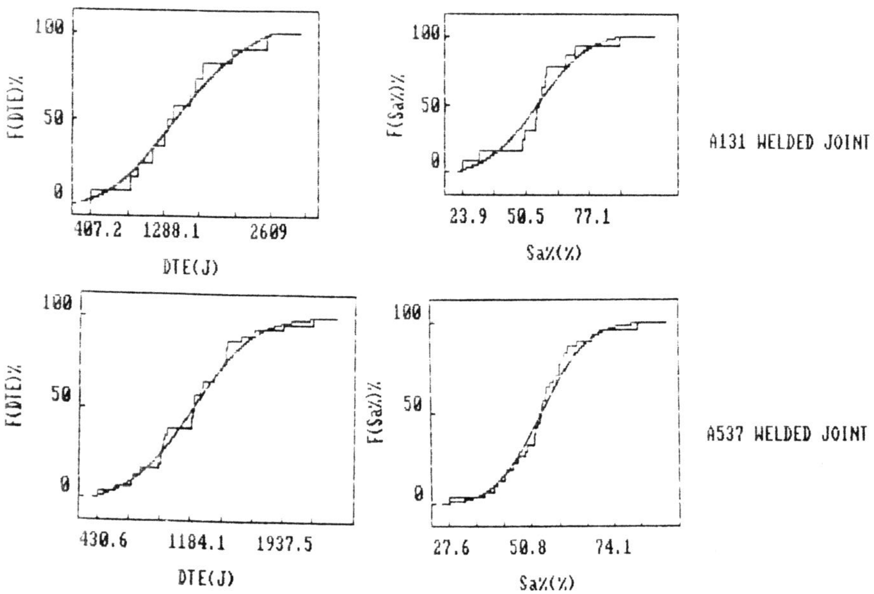

Fig.2. plot of the experimental and theoretical cumulative probability as a fuction of the DTE or Sa%

A NEW PROPOSAL USED FOR PERCENTS SHEAR Sa% DETERMINATION OF DT TEST

Although various procedures used for determining the percent shear fracture surface appearance of DT tests are introducted in some references, some of them are time–consuming and tedious and thus is not acceptable in many cases; and others in the shear rating are excessive scatter. In the present work attention was focused on establishig the new procedure for more accurate and faster determining appearance of the fractured specimens based upon Green Integration.

As we know from mathematics that on the rectangular coordinate system the plane area of any shape can be calculated with Green formula:

$$\iint_D dxdy = 1/2\oint_L xdy - ydx$$

where L is the boundary line of the area to be determined.

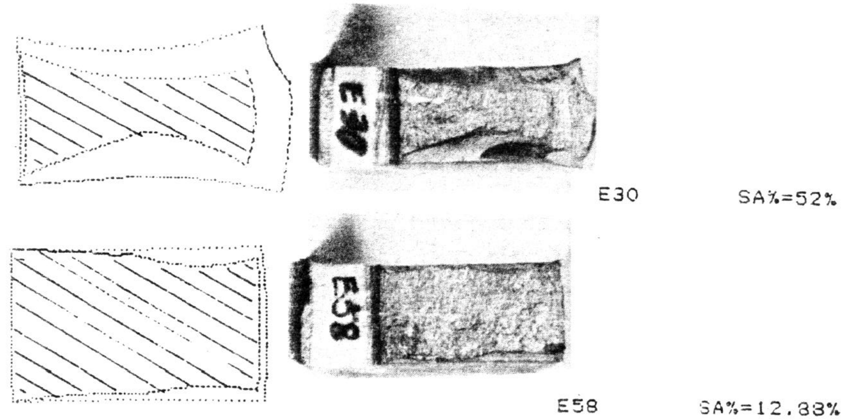

Fig.3 The typical calculated percent shear area examples by using the mothed proposed

In accordance with this equation the area integral can be transformed into the line integral, in which the line is the contour of the area. This is the theoretical foundation calculating Sa% at the present work. It is obvious that the boundary line can be divided into many straight lines and many circular arcs, and the accuracy of the calculation depends upon this segmentation. The shorter the lines and circular arcs were segregated, the more accurate calculation can be made, i.e.

$$\iint_D = 1/2\oint_L = 1/2[\int_{L_1} + \int_{L_2} + \cdots + \int_{L_n}]$$

In our calculating there are three cases:

For Circular Arcs In this case the integral can be calculated with the following equation:

$$1/2\int_L xdy - ydx = 1/2(x_0 R sin\theta - y_0 R cos\theta + R^2\theta)|_{\theta_1}^{\theta_2} \qquad (3)$$

where θ_1, θ_2: value of the angle θ between the X axis and the circular arc at starting and ending point respectively;

R: radius of the circular arc;

x_0, y_0: the coordinate points at the center of the circular arc.

For the Lines Which are not Running Parallel to Y Axis (y = Kx+B)

$$1/2\int_L xdy - ydx = 1/2\int_L (-B)dx = 1/2Bx|_{x_1}^{x_2} \qquad (4)$$

where x_1, x_2: the initial and final coordinate point of the short line on x axis resp.

For the Lines Which are Running Parallel to Y Axis

$$1/2\int_L xdy - ydx = 1/2cy|_{y_1}^{y_2} \qquad (5)$$

where y_1, y_2: the initial and final coordinate point of the short line on y axis resp.

The typical examples calculated are shown in Fig.3 in which the regions with shadow are bright smooth surfaces associated with brittle fracture.

CONCLUSIONS

A new method proposed can be used for more accurate and simple determination of the percent shear fracture surface appearance Sa%.

Beneficial effect of overmatching of weld metal in higher degree on the crack arresting (propagating) properties of welded joints was found.

At the characteristic temperature T_m either the DTE or the Sa% conforms with normal distribution for A131 and A537 steel welded joints.

ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks to National Natural Science Foundation of China for their financial support, without which the present study could never have been accomplished.

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