THE RELATIONSHIP BETWEEN NOTCH AND FRACTURE TOUGHNESS IN STEELS AND WELD METALS

K. KÁLNA and F. VINŠ

Welding Research Institute, Bratislava, Slovakia

ABSTRACT

Fracture toughness K_{IC} and/or J_{IC} characterizes material resistance to brittle fracture initiation. Steel or welded joint toughness is tested using KCV notch toughness test. It is useful to know K_{IC} - KCV relationship or the relationship of transition temperatures, for fabrication of structures resistant to brittle failure.
184 couples of data of TKC100-T28J and/or TKC150-T40J transition temperatures for various steels and weld metals were analysed. The relationships are only a little "tight", great scatter can be observed. Another relationship is valid for welded joints and another one for a steel. It is shifted approximately by 40 ^{o}C. More precise relationships can be determined for one type of steel or welded joint.

KEYWORDS

Fracture toughness, notch toughness, transition temperture, brittle failure.

INTRODUCTION

The static fracture toughness K_{IC} or J_{IC} represents the characteristic of material resistance against brittle fracture initiation. In design of structures resistant to brittle fracture the required fracture toughness of materials K_{IP} is calculated according to load level (sum of stresses S_r) and hypothetic crack size a_F employing the following equations (Begley et al., 1973).

$$K_{IP} = S_T \sqrt{\pi . a_F} \quad \ldots \text{ for } S_T/R_e \leq 1$$

$$K_{IP} = R_e \sqrt{\pi . a_F (2e/e_e - 1)} \quad \ldots \text{ for } e/e_e > 1$$

where $e = S_T/E$ - relative total strain,

$e_e = R_e/E$ - relative yield point strain

The KCV notch toughness tests are used for checking of toughness of materials including their welded joints in the plants. There is no direct correlation between notch and fracture toughness of materials. The K_{IC} test is static; the specimen is usually thick and it has a fatigue crack. The impact notch toughness test is employed; the test bar is 10 mm thick and it has a shallow notch with the acuity radius r = 0.25 mm. For a long time it is known that the steels are differently susceptible to loading rate and notch acuity. Therefore the fracture toughness K_{CJ} and notch toughness KCV characteristics of steels will be different.

Figs. 1a - 1b show temperature dependences KCV and K_{CJ} in four structural steels with different yield strength R_e = = (180 - 500) MPa. They depict transition temperatures according to notch toughness tests KCV - T28J, T40J and T50% as well as those according to fracture toughness tests K_{CJ} - TKC100 and TKC150. The definition of transition temperatures is evident from figures.

The difference between transition temperatures is as follows:

$\Delta T(28 - 100)$ = T28J - TKC100 = -15 + 87 = 72 ^{0}C

For MnVN steels according to Fig. 1b it will be:

FeE420DD ... $\Delta T(40 - 150)$ = -29 + 42 = +13 ^{0}C

FeE500DD ... $\Delta T(40 - 150)$ = -53 + 45 = -8 ^{0}C

It can be presumed, that the higher is yield strength of steel

the smaller is difference between transition temperatures T40J - TKC150. Unfortunately, the problem is more complicated.

The fracture and notch toughness values were analysed according to catalogues of welded joint mechanical properties at WRI Bratislava. Totally 184 data, i.e. 33 data for steels, 60 data for MMA welded joints, 68 data for SA and 23 data for MAG welded joints were evaluated. The regression dependences TKC 100 - T28J and TKC150 - T40J or dependences of TKC100 and TKC150 on T50% were searched for whereas the following significant physical parameters, namely material yield strength - - R_e and specimen thickness - h as well as as-welded condition or relaxation annealing of welded joints were concerned. The material structure, no doubt, belongs among significant parameters. However, the quantified data on structure are not given. It has been proved that the sufficient model for the studied regression is the quadratic equation:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{12}x_1x_2 + $$
$$+ b_{13}x_1x_3 + b_{22}x_2^2 + b_{23}x_2x_3 + b_{33}x_3^2$$

The coefficients negligible from the statistical viewpoint (on 5% level of significance) were gradually left out from the model. The results of analysis are shown in Tab. 1 where except for the coefficients b_0, b_2... b_{23} also standard deviations of approximation "s" and correlation index "r" are significant. The dependence of transition temperatures TKC100 and TKC150 on specimen thickness - h has not been confirmed; which was curprising. However, majority of input data is for h = 30 mm, only exceptionally the 20 or 60 and 120 mm thicknesses were available. It could cause, that the effect of specimen thickness was not pointed up sufficiently. The transition temperatures TKC100 and TKC150 only slightly depend on material yield strength - R_e.

When the parameters h and R_e were left out simple equations for the following steels were attained (Kálna and Vinš,1991)

TKC100 = -53.8 + 0.724 (T28J) ... s = 25.1 (Fig. 2)

$$TKC100 = -78.6 + 0.727\ (T50\%) \ \ldots \ s = 24.3$$

$$TKC150 = -38.5 + 0.743\ (T40J) \ \ldots \ s = 27.8 \quad \text{(Fig. 2)}$$

$$TKC150 = -54.5 + 0.854\ (T50\%) \ \ldots \ s = 24.3$$

Fig. 2 shows also the dependence of transition temperatures according to Marandet and Sanz (1977) designated as MS. This dependence is expressed by the equation:

$$TKC100 = 9 + 1.37\ (T28J)$$

In welded structure designing the designer often does not know which welding method will be applied. Therefore from practical aspect it is convenient to evaluate the welded joints fabricated by different welding processes in common as far as it does not lead to excessive inaccuracies. The common evaluation of TKC150 - T40J dependences of weld metals of joints fabricated by three above-mentioned welding processes is shown in Fig. 3 - WM straight line. The dependences for steel - designated as St - are also plotted in diagrams. The dependences for weld metals WM of joints are shifted by about 35 °C in comparison to dependences for steel designated as St.

The dependences for weld metals are expressed in the following equations (Kálna and Vinš, 1991)

$$TKC150 = -4.63 + 0.697\ (T40J) \ \ldots \ s = 22.4 \quad \text{(Fig. 3)}$$

$$TKC150 = -17.4 + 0.882\ (T50\%) \ \ldots \ s = 22.7$$

The highest deviations from these dependences are found in those materials which have the transition temperature $T50\% > 0\ ^{o}C$, i.e. brittle materials with low toughness.

More precise relationship between notch and fracture toughness can be determined for concrete welded joints, made by certain consumables and at given welding conditions.

Interaction of K_{CJ} and KV of these welded joints is given in Fig. 4. In general another relationships are valid for MMA joints and another ones for SA and MAG joints. For criterion value of notch toughness $K_{CJ} = 150\ MPa\sqrt{m}$ the required KV value varies within the range 28 - 66 J.

Conclusions

The relationship of transition temperatures was evaluated by means of KCV notch toughness tests, namely T28J and T50% and K_{CJ} fracture toughness tests, namely TKC100 and TKC150.

Based on the evaluation the following conclusions can be drawn:

a/ the thickness, yield strength of materials and welded joint annealing slightly affect the dependences of transition temperatures TKC100 - T28J, TKC150 - T40J or the dependences of TKC100 and TKC150 on T50%,

b/ different equations for steels and different equations for weld metals of joints should by used,

c/ the assessed relationships of transition temperatures are relatively loose, the correlation index is $r = 0.7$,

d/ more accurate relationships can be determined for selected steel grades or weld metals of joints.

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Table 1. Regression function coefficients for data of base metals and all weld metals (MMA,SA,MAG)

Factor	Base metals				Weld metals	
	TKC150	TKC150	TKC100	TKC100	TKC150	TKC150
x_1	h	h	h	h	h	h
x_2	R_e	R_e	R_e	R_e	R_e	R_e
x_3	T40J	T50%	T28J	T50%	T40J	T50%
b_o	-42,8	-71,5	-56,5	-95,2	-48,2	-73,3
b_2	-	-	-	-	0,0813	0,107
b_3	2,57	0,898	2,15	0,761	0,662	0,897
b_{22}	-	0,00012	-	0,00012	-	-
b_{23}	-0,00521	-	-0,00395	-	-	-
s	24,1	22,3	21,3	22,4	21,1	20,3
r	0,73	0,77	0,76	0,72	0,68	0,71

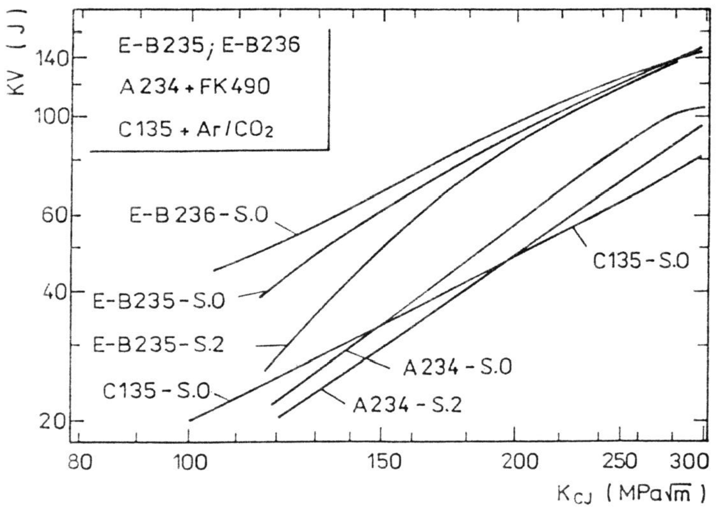

Fig. 4. Relationship of the impact energy KV to fracture toughness K_{CJ} of weld metals in FeE 355 E steel joints, designed for low temperature service

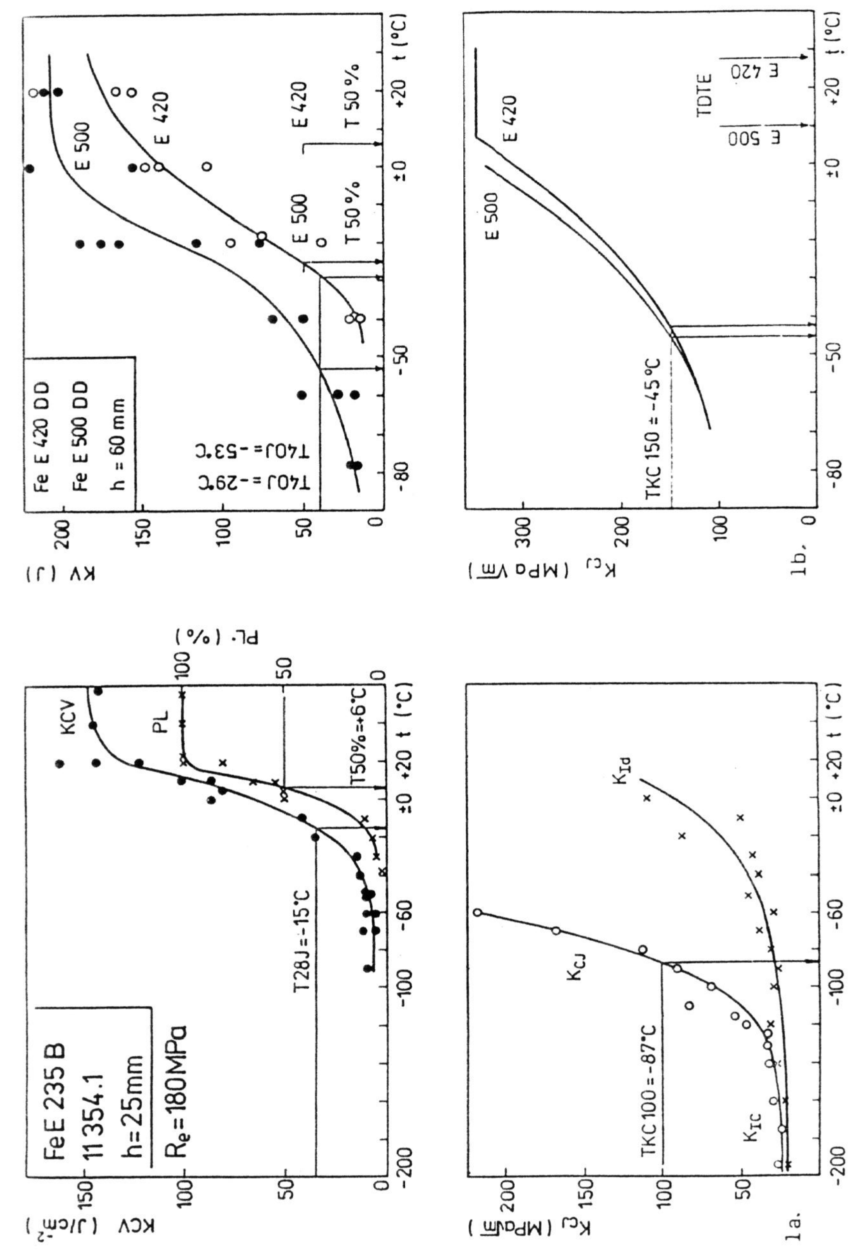

Fig. 1. Temperature dependences of notch and fracture toughness of steels with different yield strength

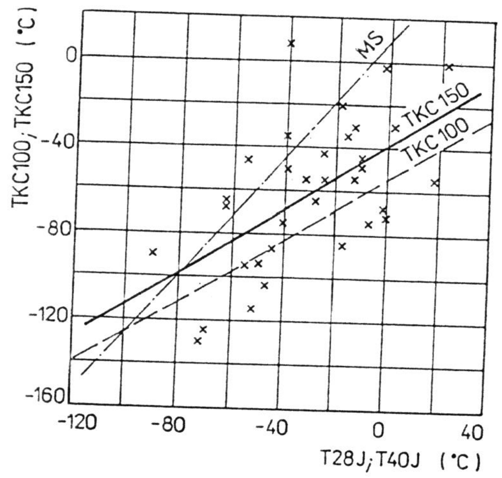

Fig. 2. Dependences of TKC100-T28J and TKC150-T40J transition temperatures for structural steels

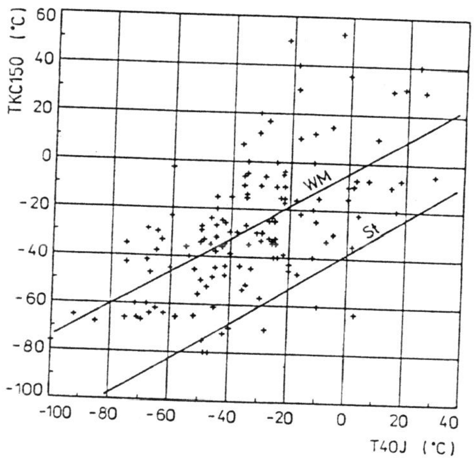

Fig. 3. Dependences of TKC150-T40J transition temperatures for weld metals of joints - WM and steels - St