ANALYSIS OF THE SPECIMEN SIZE EFFECT ON THE FRACTURE TOUGHNESS LOWER BOUND CURVES

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INTRODUCTION

An integral part of the reliability and safety assessment of WWER (PWR) nuclear pressure vessels is the quantitative estimation of the resistance against unstable crack growth during service. For this estimation it is necessary to know the fundamental material characteristics, one of which is the plain strain fracture toughness. These characteristics are required in the form of allowable values given by lower bound or reference curves.The goal of this contribution is first of all to describe the method of the fracture toughness lower bound curve determination including a "size effect" (see (1)), and to present its application to the 15Kh2MFA type of steel used for WWER 440 reactor pressure vessels.

A CONCISE DESCRIPTION OF THE METHOD

In testing specimens of different thicknesses, two types of the "size effect" are observed :
- the geometrical one that is not pronounced at plain strain fracture toughness ,K_{IC}, and at derived, K_{CJ}, values;
- the metallurgical one that strongly depends on product thickness. At the same time specimens with larger dimensions also contain more defects, thereby being more representative than smaller ones.

For this reason the simulation method of "weighted" regression has been developed to describe the effect of specimen thickness. The calculational procedure can be summarized as follows: The weights are chosen to be proportional to specimen thickness, as the initiation of brittle fracture occurs along the crack line, i.e. the working volume is proportional to the crack size (thus to the specimen thickness for the same type of specimen). The data obtained from the specimens of the same thickness form one group. These groups can be collected into larger ones,if they are inconveniently small from the statistical point of view. The simulation programme generates (for the separate groups mentioned above) fracture toughness values, the amount of which

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corresponds to their weights. From this total set of the generated and real values the lower bound curve is established and compared with the lower bound curve which corresponds to the real data set.

If any part of the lower bound curves for the total sets regularly lies below the lower bound curve for the real data, then this curve for the real data can be accepted only as a corrected c1-p1% lower bound curve. In this case the statistical levels c1, p1 are determined from the lower bound curves of the total sets, which are best covered by the c-p % curve for the real data.

APPLICATION TO THE 15Kh2MFA STEEL

For this steel the following regression line has been determined from the set of 80 fracture toughness data

$$K_{IC} = 106.7 \cdot \exp(0.0057 \cdot T_R) \qquad (1)$$

This dependence, including the lower bound curve, is shown in Figure 1, where the reference curve according to (2) is presented as well. From the comparison it is clear that the reference curve is convenient enough from the statistical point of view, however, it does not take into account the statistical uncertainties for very low and higher temperatures. From Figure 1 it can also be seen that it is just the 98-98 % lower bound curve which covers all the data. Figure 2 shows that this curve is recommended according to our simulation procedure as the corrected 96-96 % lower bound curve.

USED SYMBOLS

K_{IC} = plain strain fracture toughness ($MPa.m^{1/2}$)

K_{CJ} = fracture toughness (J-integral) ($Mpa.m^{1/2}$)

T_R = reference temperature (^oC)

REFERENCES

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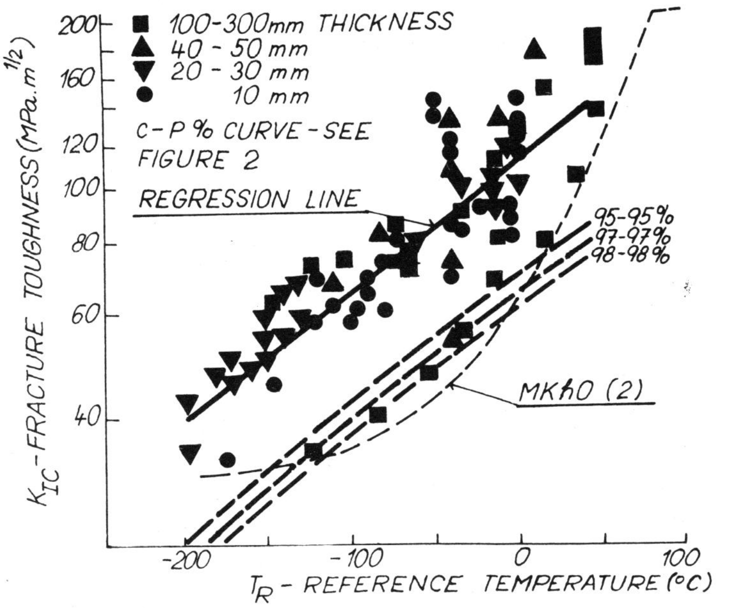
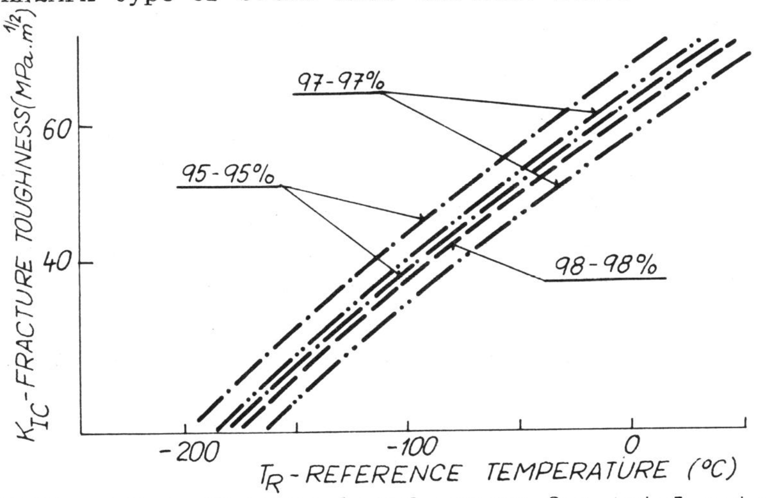


Figure 1 Comparing the lower bound curves for the 15Kh2MFA type of steel with the MKhO reference curve



=·:= the cover of lower bound curves for total sets
— — c-p % lower bound curve for real data
c-p % curve = c % confidence that p % of the population will equal or exceed this curve

Figure 2 Comparing the lower bound curves for total sets and real fracture toughness data