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EXPERIMENTAL CORRELATIONS BETWEEN DYNAMICAL TOUGHNESS CHARACTERISTICS OF PRESTRAINED PRESSURE VESSEL STEELS

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INTRODUCTION

It is modern practice to manufacture thick walled pressure vessels by welding. These must function with maximum security at low temperature. This need has given impetus to research on new steels with elevated mechanical properties and to the search for new testing methods and criteria with which to characterise more significantly the mechanical toughness of different materials.

Progress made in the last two decades in fracture mechanics makes it possible to define the toughness characteristics taking into account the stresses and strains in the immediate vicinity of a crack-like defect [2, 6]. Since, however, a great amount of data and experience was gathered from the older, classic methods of acceptance tests of steels, one can raise justifiably the question of a statistical correlation of the classic, conventional measurements with the new parameters of fracture mechanics. In this way the old data could be used in control and design according to the prescriptions of the new test methods.

STEELS TESTED

Tests were performed on steels of international classification D and E. The steels were of qualities R2 and R3 according to the Romanian standard STAS 2883/2-70 and were delivered as rolled and normalized plates in 22 mm and 32 mm thickness. The chemical composition and mechanical properties are presented in Table 1.

FACTORS INVESTIGATED AND RESEARCH PROGRAMME

In view of the service conditions of the steels tested and taking into account the principal factors leading to brittleness during the manufacture and working processes [5] the influences of test temperature and cold prestraining were examined.

In investigating the influence of temperature (T) the range 213 to 293K, was considered, so as to include the whole service range, and, in testing the influence of cold prestraining (ε_p), 5 levels in the range 0 to 10%, which cover the whole domain of plastic deformation of the investigated steel were used. In reality, however, the maximum deformation in the extreme fibres is limited to 5%.

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The experimental programme detailed in Table 2 conforms with the principal measurements of dynamical toughness determined in our work. In establishing the complete programme it was considered important to apply the same testing conditions, especially the same stressing rate, and to use the criterion of the dynamic notch bend test (ISO-V), which is unanimously accepted to day for most steel structures in service at low temperature [4], in order to relate the old, conventional measurements with the new ones, such as those based on fractures mechanics. A critical COD value of 0.1 mm was assumed for the purpose of comparison and correlation and specimen dimensions were the same throughout the tests.

The test specifications used are also listed in Table 2. The COD tests were performed in three point bend by applying dynamical stresses with sequentially increasing stress values [1]. The milled notch had depth 2 mm and width 0.2 mm. The value of δ_c was determined from the rotation of the sides of crack:

$$\delta = 2c - (b+\delta_o) .$$

The distances b and c between two pairs of marks (Figure 1) are measured optically after each dynamical stress application (an average 4 - 6 stresses are needed to fracture a specimen). The value of NRC was determined from repeated microscopic observation with precision ± 0.005 mm and the percentage of brittle fracture was determined according to ASTM A 370-72.

ANALYSIS OF RESULTS

Five different experiments were performed for each T and ε_p value. A marked dependence of toughness parameters upon T and ε_p was found. For instance the 28J transition temperature from the ISO-V test showed an increase of 3-4K for a 1% increase in plastic deformation with small differences between the steels (Figure 2).

Taking only the correlations which can be generalized for both the steels investigated one can establish the following general relations: KCV = f(KCU2), NRC = f(KCV), Cr = f(KCV), KCV = f(δ_c), NRC = f(δ_c) and NRC_{KCV} = f(NRC_{COD}). The experimental points representing the pair of parameters in these correlations for both the steels are shown in the above order in Figures 3 - 8. By statistical analysis, it was established that all correlations are linear. The values of the regression parameters are given in Table 3.

CONCLUSIONS

Comparison with published data shows that the regressions established have general validity. They are independent of the test temperature, T, and cold prestraining, ε_p. The high values of the correlation coefficients give weight to their validity (Table 3). Correlation (4) which links classical and nonconventional toughness measurements is especially important.

The results appear to show that, in contrast with other results [3], the relation NRC = f(δ_c) has validity up to δ_c = 0.75 mm. Using the regressions from cols .2 and 5 (Table 3) it is possible to identify a good correlation

between the NRC values obtained on KCV and COD specimens. For the range examined it was established that $NRC_{KCV} > NRC_{COD}$, excepting low values of NRC (NRC < 2.5 - 3% see Figure 8).

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Table 1

Steel	Chemical Composition (%)						YS	UTS	δ_{10}	RA	KV - Energy
	C	Mn	Si	P	S	Al	(MPa)	(MPa)	(%)	(%)	(J)
R2	0.19	1.07	0.25	0.011	0.012	0.036	331	461	28.5	64.3	43 at -20°C
R3	0.20	1.40	0.23	0.013	0.016	0.030	434	598	21.5	60.0	45 at -40°C

Table 2

Type of Test		Dynamic Bending Test with Specimens		
		KCU 2	ISO-V	COD
Influence Factor	Prestraining	ε_p = 0; 2.5; 5; 7.5; 10%		
	Temperature	T = 213 to 293 K		
Determined Characteristics		KCU 2	KCV,NRC,Cr	δ_c, NRC
Test Conditions According to		STAS 1400-75 STAS 6833-70	ASTM A 370-72 ASTM E 23-72 STAS 10026-75 STAS 7511-73	BS DD19/72

- δ_c = critical crack opening displacement,
- NRC = notch root contraction at the base of the COD and ISO-V-notch,
- Cr = percentage of crystalline (brittle) fracture,
- KCV and KCU2 = impact value from ISO-V and Mesnager bending test specimens.

Table 3

Statistical Parameters	Correlated Characteristics* y = ax+b					
	KCV = f(KCU2)	NRC = f(KCV)	Cr = f(KCV)	KCV = f(δ_c)	NRC = f(δ_c)	NRC_{KCV} = f(NRC_{COD})
	1	2	3	4	5	6
a	0.88	1.14	-17.76	10.15	7.47	1.61
b	-2.17	1.14	124.46	0.38	2.13	-2.07
Correlation Coefficient r	0.95	0.90	0.94	0.90	0.91	0.85

*KCV and KCU2 in 10^5 J/m², Cr and NRC in %, δ_c in mm

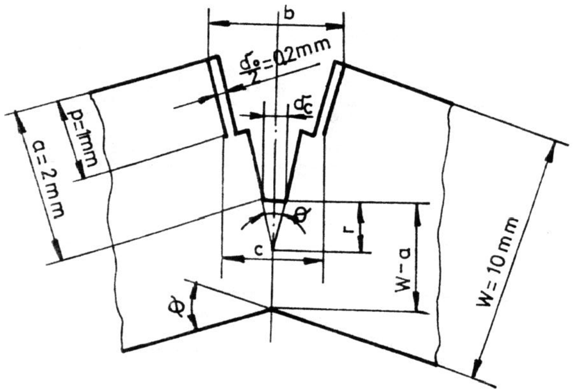

Figure 1 Method of COD Measurement

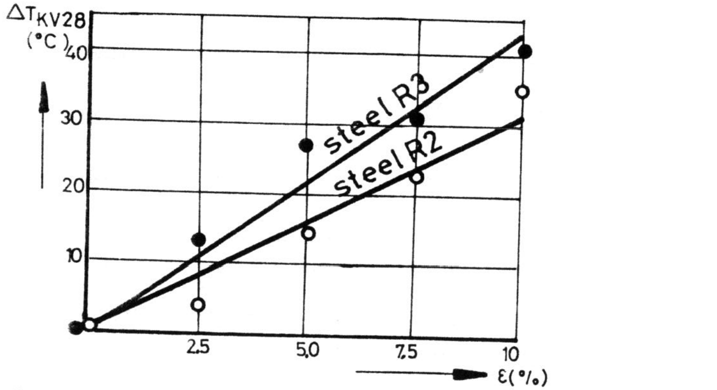

Figure 2 28J Transition Temperature versus Prestrain Level

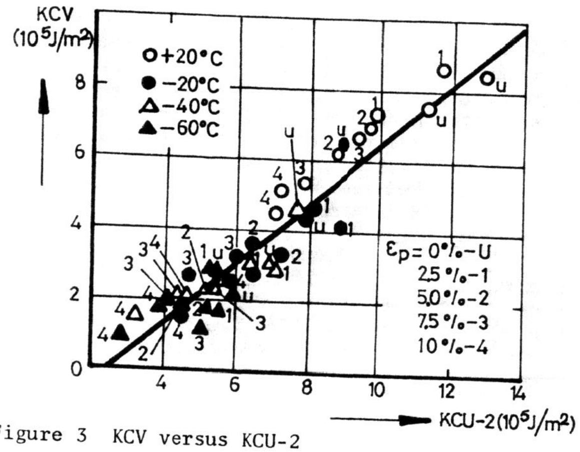

Figure 3 KCV versus KCU-2

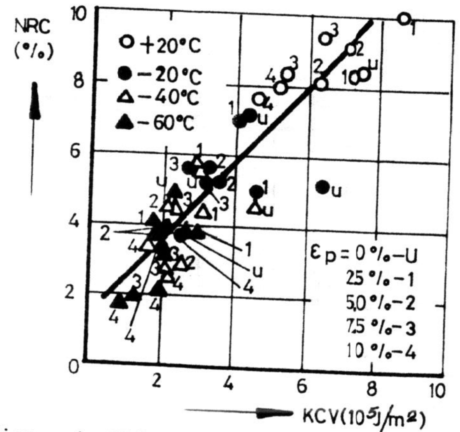

Figure 4 NRC versus KCV

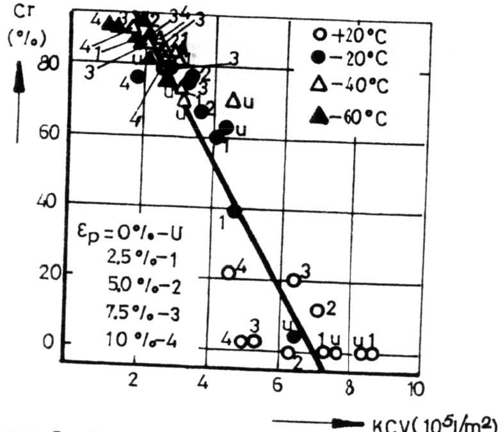

Figure 5 Cr versus KCV

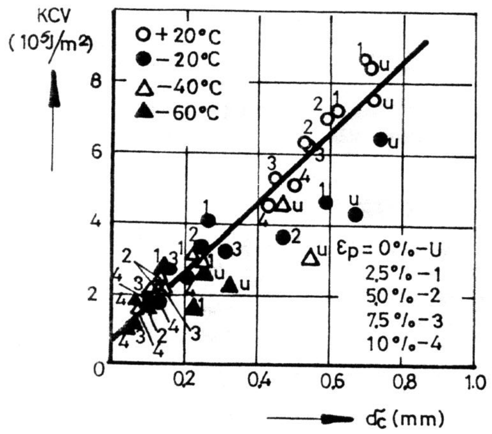

Figure 6 KCV versus δ_c

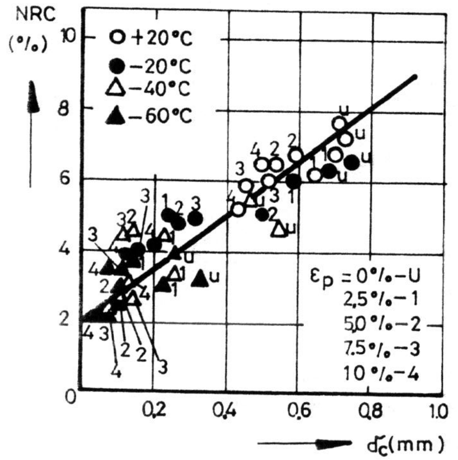

Figure 7 NRC versus δ_c

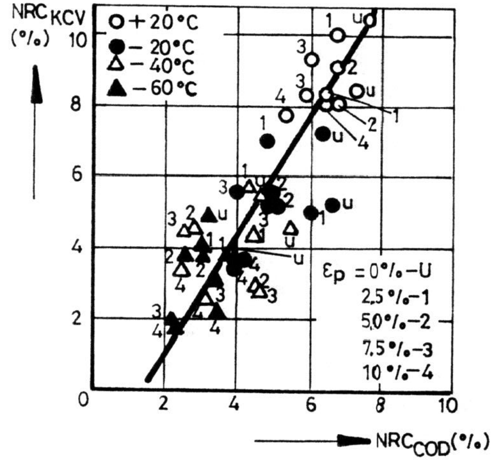

Figure 8 NRC_{KCV} versus NRC_{COD}