LATERAL EXPANSION OF CHARPY-V-SPECIMENS AND FRACTURE BEHAVIOUR OF STEELS

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Correlation of lateral expansion and impact energy is discussed. In upper shelf this correlation depends on strain hardening behaviour. H linear connection between lateral expansion and fracture deformation energy is described. With this deformation energy K_{IA} can be estimated by means of the aquivalent energy method.

INTRODUCTION

Although fracture mechanics great sucess,impact tests like the charpy-V-notch test are the most widley used toughness tests. This fact is caused in the cheap specimens and the simple performance of these tests. There have been made a lot of attempts in last time to get beside impact energy additional information from this test. Gross and Stout (1) stated that the lateral expansion is a more suitable criterion to determinate toughness than the impact energy. Actually , the lateral contraction should be a better measure of notch ductility, but lateral expansion at the compression side of the specimen correlates well with the contraction and is easier to be measured.

Williams and Croll (2) found a linear correlation between impact energy and lateral expansion dependent on steel strenght. They gave the regression equation:

$$LE = \frac{Av - 0{,}01505\ Rm + 9{,}0329}{0{,}06332\ Rm + 20{,}8543} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

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Meyer and Schwarz (3) confirmed this correlation, they could point out that there is no dependence of steeltype (figure 1). Pawelski et.al.(4) and Robiller (5) found other linear functions.

The correlation given in equ.(1) is only valid for the transition area. In upper shelf Williams and Croll (2) stated a deviation to lower lateral expansions. Meyer and Schwarz (3) also found this deviation but only for steels of lower strenght, for highstrengthsteels they stated a deviation to higher lateral expansions.

EXPERIMENTAL

Charpy test

The charpy tests were carried out according to the German standard DIN 51222, only charpy-V-notch specimens were used. The determination of the lateral expansion was carried out according to ASTM A 370. The percentage of crystalline fracture surface was estimated by visual inspection. The used apparatus had an energy content of 300 Joule. The pendulum velocity in position of the specimen was 5.6 meters per second.

Instrumented Charpy tests

For this examinations a standardized apparatus was equiped with the necessary electronics for measurement of power versus time. The area under the so obtained curve is equivalent to the impact-impulse. To get the impact energy it is necessary to translate the measured time into way.This was done by using the method according to D.R.Ireland (6).

Determination of strain hardening exponent

To explain the deviation of lateral expansion in the region of upper shelf energy it was necessary to carry out impact tensile tests with a deformation velocity similar to that of charpy tests to determinate the strain hardening exponent. The test apparatus and procedure is described by W.Marschal (7).

K_{IJ} Measurements

To obtain a comparison between results from lateral expansion and fracture mechanical values. J-integral measurements were carried out, bending specimens were used. A special description of the test method and specimen geometry is given by W.Meyer, A.Lammer and W.Schwarz (8).

Tested Steel Grades

All mentioned tests were carried out at the four steelgrades specified in Table 1.

TABLE 1 - Chemical composition of the mainly tested steel grades

Steelgrade	%C	%Si	%Mn	%P	%S	%Cr	%Mo	%Ni
C 35	0,32	0,25	0,65	0,028	0,035			
28NiCrMoV85	0,28	0,28	0,40	0,010	0,004	1,22	0,46	2,02
X5CrNiCuNb174	0,04	0,31	0,38	0,018	0,009	15,85	0,18	4,75
X22CrMoV121	0,23	0,33	0,67	0,017	0,006	11,53	1,05	0,70

Each of these steelgrades was tested at three or four steps of tensile strength between 800 and 1200 $N.mm^{-1}$. For some tests additional steels were used.

RESULTS AND DISCUSSION

LE at upper shelf energy

Figure 2 shows lateral expansion versus impact energy for the steel X5CrNiCuNb174. In the series of samples with the lowest ultimate tensile strength a negative deviation from the linear function is evident for upper shelf energy. Series with higher tensile strength show positive deviation. This statement is valid for all tested steels. It was found a linear correlation between this deviation and the tensile strength, but the slope of this function is not independent from tested steelgrade.

Krisch and Gramberg (9) measured the increase of hardness near the fracture surface of tested charpy-specimens. To see whether there is a connection between the deviation and the strainhardening behaviour of the steels, the strainhardening exponent obtained from the mentioned impact tensile tests was compared with the deviation of lateral expansion in upper shelf region. Results are shown in figure 3. A rather good connection between these two values is evident. Only the behaviour of the steelgrade X22CrMoV121 is somewhat different. This may depend on the differences in grainsize, because the specimens of this grade had grainsize of 5 according to ASTM against 8-9 at the other grades. It is known that there is a influence of grainsize on strain hardening exponent (10) (11).

It makes no difficulty to explain the negative deviation at the lower tensile strength with strain hardening. The slope for high strength steels indicates a beginning of strain hardening at the transition temperature and a certain recovery in the upper shelf, this could be caused by the short free ways of the dislocations.

Instrumented Impact Tests

The evaluation of these tests was carried out according to Wellinger et.al.(12). A comparison of the so measured amounts of energy with lateral expansion led to a connection between lateral expansion and deformation energy according to Nierhoff and Schmidtmann (13). This in figure 4 shown connection seems to be independent from steelgrade, hardening mechanism and mechanical properties.

The following regression equation was obtained:

$$A_d = -7,13 + 66,91.LE \qquad (2)$$

Aquivalent Energy and J-Integral

It was of interest to use the thus obtained knowledge of deformation energy to make an estimation of the K_{IA} value according to the method of Witt and Mager (14). A calculation considering the specimen geometry led to

$$K_{IA} = 709.\sqrt{-7,13 + 66,91.LE} \qquad (3)$$

The course of this function is the line in figure 5. This figure shows also the results of seperatly carried out K_{IJ} measurements using bigger 3 point bendingspecimens(8). The fracture surfaces of these K_{IJ} specimens showed ductil fracture therefore one had to compare the K_{IJ} values with lateral expansion values got from impact tests at upper shelf energy. A rather good agreement between the found K_{IJ} values and the K_{IA} values calculated according to equation 3 is apparent.

It is to be noticed that similar considerations concerning fracture energy and toughness were made by Gillemot (15) for notched tensile specimens.

CONCLUSIONS

It will be necessary in further work to dicuss some aspects of this results as for instance the influence of specimen geometry.

But it seems remarkable that according to figure 5 the connection between the fracture mechanical value and lateral expansion shows no dependence from chemical composition, hardening mechanism or similar material properties. So the measurement of lateral expansion offers a good possibility for estimation of fracture mechanical values without expensive and complicated experiments.

SYMBOLS USED

LE =lateral expansion (mm)

A_v =impact energy as measured at charpy-V-test (J)

R_m =ultimate tensile strength ($N\ mm^{-1}$)

A_d =fracture deformation energy (J)

K_{IA} =K_I value determinated by aquivalent energy method ($N\ mm^{-3/2}$)

K_{IJ} =K_I value determinated by J_{IC} measurement ($N\ mm^{-3/2}$)

d =deviation of LE from the linear function (equation 1) (mm)

REFERENCES

1. Gross,I.H.,and Stout,R.D.,1958,Welding Journal,37,151
2. Williams,I.G.,and Croll,I.E.,1975,The journal of Australian Institute of Metals,20,159
3. Meyer,W.,and Schwarz,W.,1981,Berg-und Hüttenmännische Monatshefte,126,84
4. Pawlewski,O.,Gopinathan,V.,and Hagedorn,K.E.,1980, Arch.Eisenhüttenwes.,51,435
5. Robiller,G.,1980,Stahl u.Eisen,100,1132
6. Ireland,D.R.,1974,ASTM STP,563
7. Marschal,W.,1982,Diplomarbeit Leoben
8. Meyer,W.,Lammer A.,Schwarz,W.,1980, Proceedings of 12. Sitzung Arbeitskreis Bruchvorgänge Freiburg,BRD.

9. Krisch,A.,andGramberg,U.,1977,Arch.Eisenhüttenwes.,48,105

10. Klunker,H.,Hening,W.,and Voigtlander,J.,1975,Neue Hütte,29, 589

11. Pysz,G.,Naether,G.,and Krumnacker,1979,Metall,33,1061

12. Wellinger,K.,Proger,M.,and Vasonkis,G.,1973,Z.f.Werkstoff-technik,4,4

13. Schmidtmann,E.,and Nierhoff,H.,1979,Arch.Eisenhüttenwes., 50,213

14. Witt,J.F.,and Mager,J.R.,1971,Nuclear Design,17,91

15. Gillemot,L.F.,1976,Engeneering Fracture Mechanics,8,239

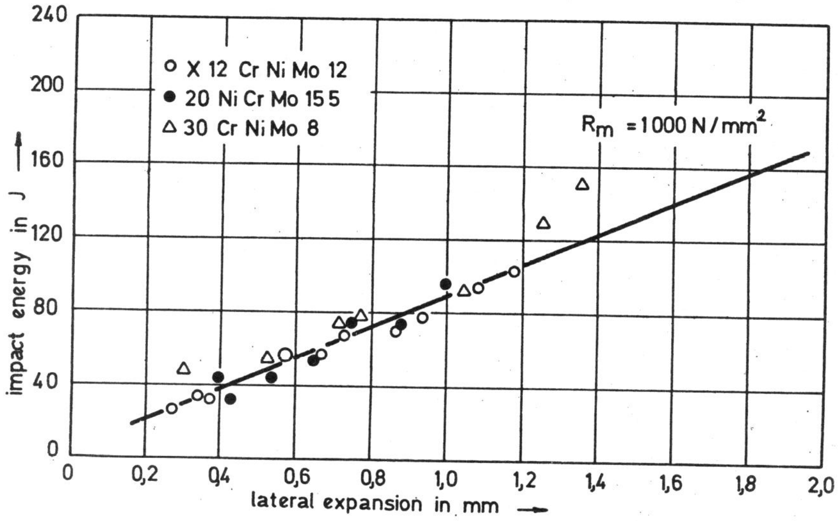

Figure 1 Lateral expansion plotted against impact energy for different steel grades

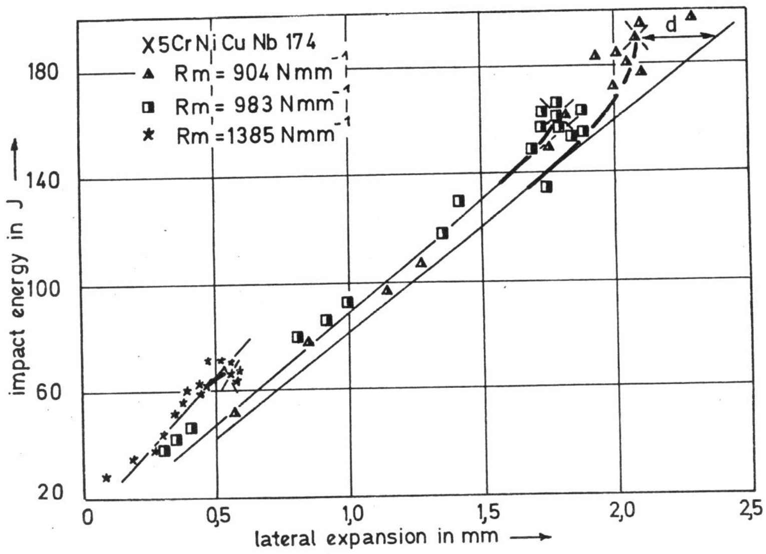

Figure 2 Lateral expansion and impact energy, deviation in upper shelf

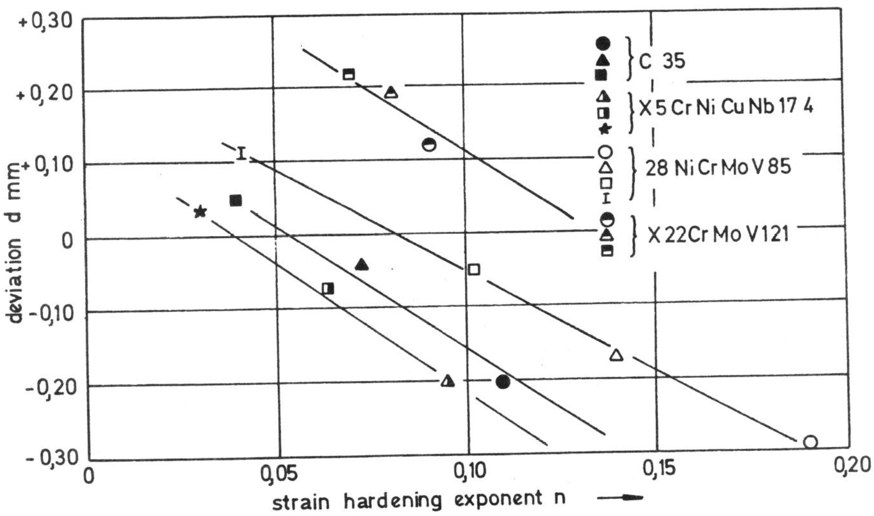

Figure 3 Deviation in upper shelf versus strain hardening exponent

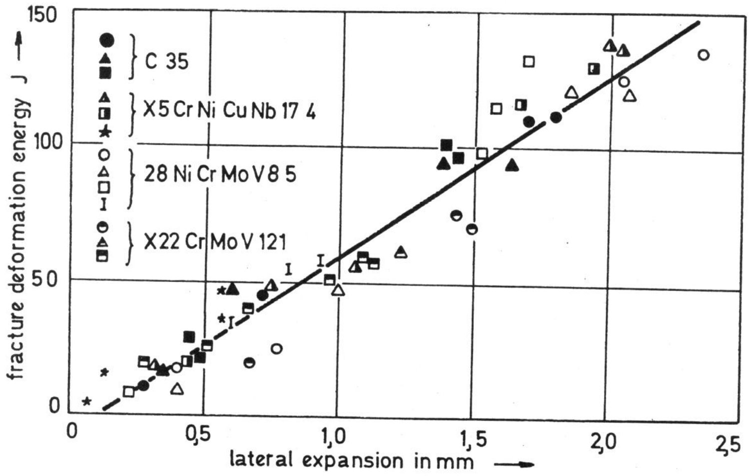

Figure 4 Connection between fracture deformation energy and lateral expansion

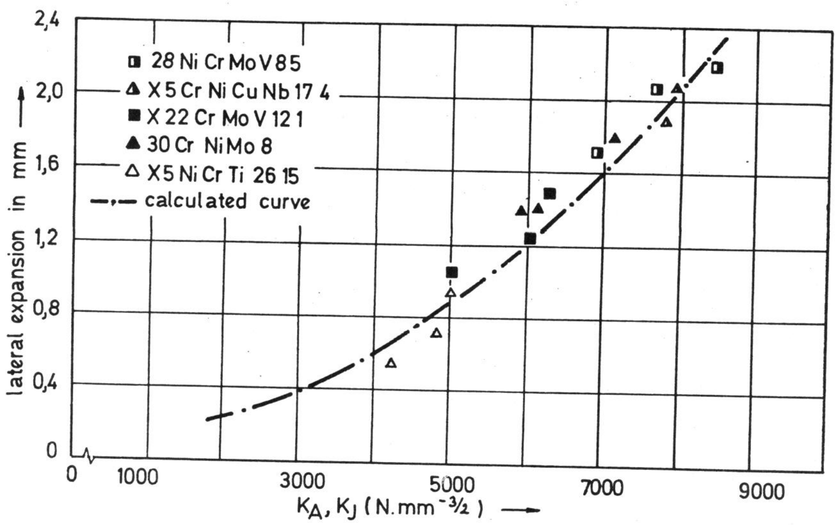

Figure 5 Calculated K_{IA} and measured K_{IJ} values plotted against lateral expansion