QUANTITATIVE FRACTOGRAPHIC ANALYSIS OF DUCTILE FRACTURE OF THE LOW CARBON STEELS

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In the paper the results of quantitative fractographic evaluation of fracture and its relationship to mechanical properties of low carbon steel is presented. Investigations were carried out for laboratory melts of low carbon steel and commercial HSLA steel grades with different volume fraction and morphology of Nonmetallic Inclusions. A quantitative fractographic method of ductile fracture evaluation has been shown useful to describe an influence of Nonmetallic Inclusions on mechanical properties.

INTRODUCTION

The ductility of low carbon steel is strongly influenced by the properties of both: the matrix and the Nonmetallic Inclusions (NJ). NJ play a dominant role in ductile fracture process, and the volume fraction, nature, shape, chemical composition and distribution of NJ are of importance [1]. It was found that there is a clear influence of the a.m. NJ features on mechanical properties (CVN, COD, CTOD, J_{Ic} and ε_f) of the low carbon steel [2, 3].

Quantitative fractography allows to describe some features of ductile fracture process through simultaneous measurements made on projections and profiles of fracture surfaces. Although there were a lot of works carried out in this fields their results did not provide so far, a general model connecting quantitative features of fractures with mechanical properties of steel.

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This makes the quantitative comparison of fracture mode difficult [4-6]. The influence of the NJ on the ductile fracture process can be describe by the parameter W' as follows:

$$W' = W \times R_L \tag{1}$$

In equation (1), W is a ratio of the average void size to the average NJ size (average void size, is measured on a fracture surface while average NJ size is measured on a cross section of the sample). R_L parameter takes into consideration the roughness of fracture surface.

The goal of this work was to experimentally verify the method of quantitative evaluation of the ductile fracture mode for different matrices of the carbon steels.

EXPERIMENTAL PROCEDURE

TABLE 1 - Chemical composition of the investigated steels (mass percent).

Steel	C	Mn	Si	S	P	Al	O	Type of NI
1	0.020	0.51	0.014	0.011	0.006	0.0040	0.029	I
2	0.025	0.48	0.009	0.011	0.006	0.0080	0.002	II/2
3	0.017	0.50	0.010	0.032	0.004	0.0070	0.003	II/2
4	0.010	0.51	0.025	0.028	0.007	0.0070	0.003	II/2
5	0.020	0.50	0.011	0.047	0.006	0.0060	0.004	II/2
6	0.018	0.52	0.005	0.047	0.003	0.0080	0.003	II/2
7	0.010	0.40	0.021	0.037	0.007	0.0035	0.225	I
8	0.012	0.38	0.030	0.052	0.008	0.0040	0.215	I
9	0.015	0.55	0.007	0.063	0.006	0.0080	0.003	II/2
10	0.010	0.57	0.004	0.080	0.006	0.0040	0.214	I
11	0.010	1.48	0.011	0.150	0.005	0.0050	0.010	II/1
12	0.025	1.50	0.011	0.150	0.005	0.0060	0.003	II/2
13	0.160	1.38	0.360	0.011	0.013	0.0040	0.008	
14	0.160	1.40	0.350	0.023	0.013	0.0050	0.002	
15	0.170	1.40	0.340	0.024	0.011	0.0050	0.006	

Samples taken from twelve laboratory melts of low carbon steel with different volume fraction distribution and shape of NJ and three commercial melts of HSLA steels have been used in this investigations - table 1. From each sample , longitudinal and transverse tensile specimens (Fig.1a) were machined. After tensile tests these specimens were used for fractogaphic investigations. As a measure of ductility, a true strain at fracture $\varepsilon_f = \ln A_0/A_f$ were used. SEM micrographs of fractures (magn.2000x) were used to determine average dimple size of ductile fracture by means of computer image analysis system. After coating of the fracture surface, a vertical sections were cut and prepared metalographically for examination. The profiles of the fracture surfaces were digitized using a computer system at an image magnification 1500x.In order to determine a stereological parameters of NJ, a measurements for longitudinal and transverse specimens were made using Quantimet 720 analyser. In Fig.1 a schematic diagram indicating an orientation of samples and fracture surfaces with respect to main axis elongated inclusions is shown.

RESULTS AND DISCUSSION

In Fig.2 the influence of volume fraction, V_v, of sulphides on tensile ductility is shown. As it is shown longitudinal specimens have slighty higher values of true strain ε_f in comparison with transverse specimens; this difference depends on type of sulphide inclusion - table 1. In Fig.3, the changes of W' parameters value as a function of volume fraction, V_v of sulphide inclusions is shown. In Fig.2 and Fig.3 the bar graphs represent an actual values of ε_f and W' measured for a given volume fraction of inclusions while dashed and dotted lines represent trend lines for longitudinal and transverse samples respectively. Both figures shows good qualitative correspondence with each other. Relationship between true strain to fracture, ε_f, and parameter W' is shown in Fig.4. This figure also indicates a good agreement of the results obtained for laboratory melts of low carbon steel with those obtained for commercial HSLA grades (black points in Fig.4). Quantitative confirmation of usefullness of the fractographic method is straightening curves W and W' vs. true strain to fracture. Moreover it verifies the rightnes of using R_L parameter to transformation flat SEM pictures to three dimensional configuration of fractures (straightening W' curve vs. ε_f with slope approach 45^o).

SYMBOLS USED

W = D/d
D = dimple size (μm)
d = Nonmetallic inclusion size (μm)
R_L = linear roughness

REFERENCES

1. D.Dod, Y.Baj, Ductile Fracture and Ductility, Acad.Press Inc. London, 1970
2. F.B.Pickering, Physical Metallurgy and Design of Steels, London, 1978.
3. A.Zaczyk, W.Dziadur, S.Rudnik, IV European Symposium for Stereology, Göteborg, 1985 Proc. pp.126-129.
4. L.Wojnar, Quantitative Fractography, Monography Nr 2, 1990, Cracow Techn.Univ.
5. D.Broek, Engineering Fracture Mechanics, Vol.5, 1973, pp.55-66.
6. W.Dziadur, Report to Grant No 3-127-91-01.

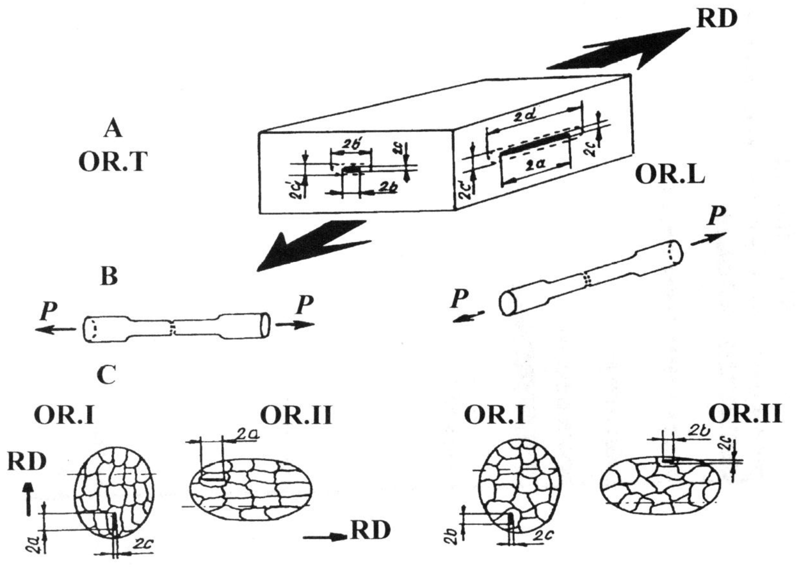

Figure 1 Orientation of samples and fracture surfaces with respect to main axis of elongated inclusions.

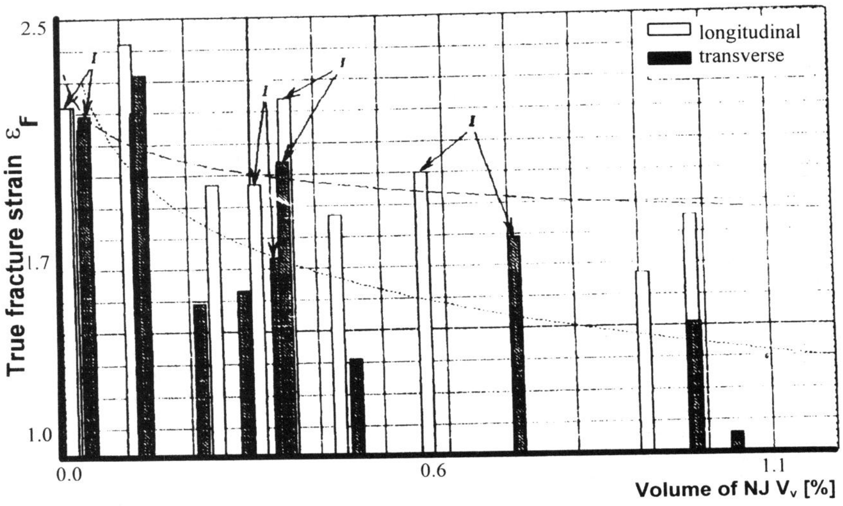

Figure 2 Effect of volume fraction inclusions on tensile ductility

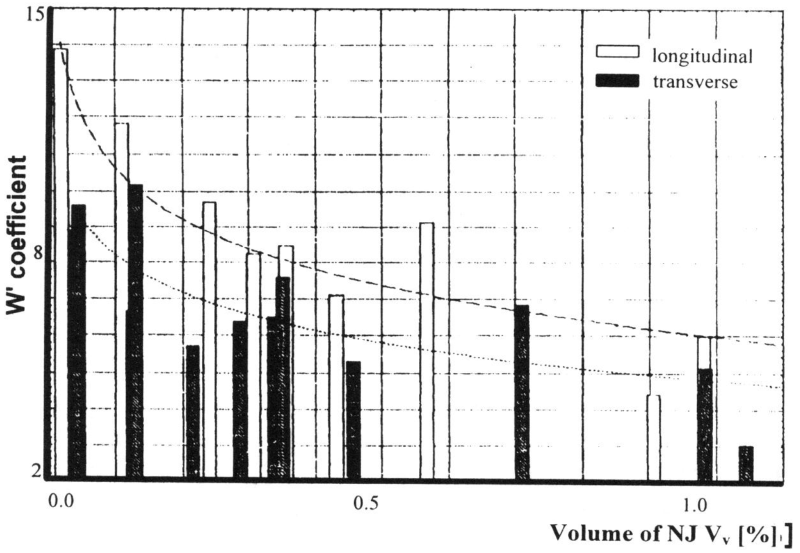

Figure 3 Effect of volume fraction inclusions on fractographic W' parameter

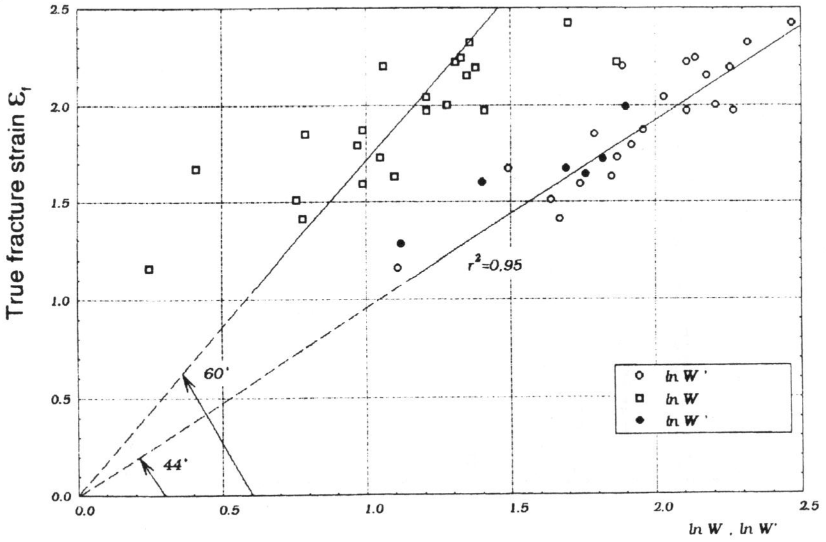

Figure 4 Dependence between true strain to fracture ε_f and fractographic W' parameter