FATIGUE LIFE OF HARDFACED ELEMENTS

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In this work an attempt was made to find a relationship between the features of the hardfaced layer over 45 steel cylinders, and their fatigue properties. A model approach has been made in the paper to assess the effect of welding defects on fatigue durability of elements with a hardfaced surface layer. This approach in form of mathematical model has been verified with the results of experimental fatigue tests of specimens. An effect of weld metal mechanical properties upon the fatigue life and the fatigue strength has been described as well.

INTRODUCTION

Prediction of safe and failure-free life of technical devices is one of important issues in the industrial practice and, hence, the designers have to apply an appropriate methodology to the material feature selection. It is necessary, therefore, to use the durability criteria corresponding with the given working conditions as for instance in case of the cyclic loading which induce fatigue of machine and equipment elements. Fatigue life prediction of hardfaced elements is one of such problems.

Hardfacing is usually performed to regain the original shape and dimensions of worn machine parts, or to obtain some physical properties of the part surface. The fatigue durability of the hardfaced elements may be affected by such factors as the defects in the hardfaced layer, its microstructure and mechanical properties. The processing conditions i.e. the applied method and technique of hardfacing, as well as the thickness of the welded layer have some influence on the number and type of defects.

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On the other hand, the mechanical properties of the surface layer are related to the microstructure of the weld.

This work concentrates upon the problem of hardfaced elements fatigue life, associated with mentioned features of the layer.

RESEARCH PROGRAM AND RESULTS OF THE FATIGUE TESTS

The programme comprised fatigue investigations of 45 steel cylinders (specimens) with surface layer made with a various weld metal. The investigation of specimens without layer have been carried out as well. The double-side pure bending fatigue tests and the torsion-bending fatigue tests have been applied. In order to determine the influence of welding defects on the fatigue durability of hardfaced elements the double -side pure bending fatigue tests has been used. The torsion-bending fatigue tests made possible to estimate the influence of the weld metal mechanical properties on the specimen fatigue life.

Figure 1 presents S/N curves (fatigue curves) of 45 steel specimens without layer and specimens hardfaced with EB 1.50 electrodes (chemical composition of weld metal: 0,08% C, 1,1% Mn, 0,4% Si, properties: $R_e > 420$ MPa, $R_m = 550 - 620$ MPa). The weld metal had properties and structure like the base material in this case. The padding welds had some microvoids.

TABLE 1 - Chemical Composition of Weld Metal of Electrodes and their Mechanical Properties.

Electrode No.	Type	Chemical Composition [%] C	Mn	Si	Cr	Mo	Mechanical Properties R_e[MPa]	R_m[MPa]	HV
1	45 steel	0.43	0.6	0.25	-	-	360	600	240
2	ESCrMoR	0.07	0.7	0.30	0.9	0.6	420	530	189
3	SpG3S1+M2.1	0.10	1.5	0.90	-	-	410	470	171
4	SGMo+M2.1	0.10	1.1	0.70	-	0.5	430	545	223
5	Sp40G2H1+M2.1	0.35	1.0	1.2	1.2	-	700	800	280

Note: M2.1 - 2% Ar + 18% CO_2

Hardfaced layers on the specimens devoted to torsion-bending fatigue tests have been prepared with electrodes which are characterised in Table 1. Torsion-bending fatigue test results have been shown in Table 2.

TABLE 2 - Fatigue Strength and Number of Cycles to Failure as a Function of the Weld Metal Mechanical Properties.

No.	R_m [MPa]	HV	Z_{go} [MPa]	Fatigue Life N [cycles] (applied stress range $\Delta\sigma$=375 MPa)
1	600	240	314	100000
2	530	189	275	186000
3	470	171	250	35000
4	545	223	241	55000
5	800	280	356	1100000

ANALYSIS OF THE RESULTS OF STUDIES

An interpretation of Palmgren (1) and Miner (2) hypothesis, based upon the analysis of the crack growth characteristics presented in work of Miller (3), is applied here. Taking the initial length of a crack in the material without any hardfaced layer as l_o, the size of the material defect as l_1, and the crack considered as the damage criterion as l_f, one may correlate the above mentioned values with the number of loading cycles and the characteristics of crack development. To this aim the following equation have been applied:

$$\frac{dl}{dN} = A(\Delta\sigma)^m l \tag{1}$$

The results of fatigue test were expressed in the form of mathematical models and approximated with the equation:

$$\Delta\sigma = C - n\log(N+1) \tag{2}$$

Following Palmgren and Miner hypothesis in the form:

$$\frac{N_1}{N_f} + \frac{N}{N_f} = 1 \tag{3}$$

after transformations the number of cycles to failure of specimens with hardfaced surface layer has been calculated as a function of the length of defects existing in the weld (l_1):

$$N = \left[1 - \frac{\ln(l_1 / l_0)}{\ln(l_f / l_0)}\right]\left(10^{(C-\Delta\sigma)/n} - 1\right) \tag{4}$$

The fatigue diagram shown in Fig.1 have been drawn taking as a basis Equation (4). The line (t) in Fig.1 corresponds with the l_o as the size of dislocation cell, l_1 as the thickness of the padding weld and heat-affected zone. The line (t) (Fig.1) shows some convergence with the results of fatigue tests of the hardfaced samples.

Relationships between the mechanical properties of the weld metal and the fatigue properties of the specimens have been shown on the Fig.2 and Fig.3. These results were approximated with the equations:

$$Z_{go} = 0.44 R_m + 29.372\,, \tag{5}$$

$$\log N = 0.004 R_m + 2.677 \tag{6}$$

The diagrams in Fig.2 and Fig.3 show that the fatigue durability and the fatigue strength of the tested specimens can be expressed as the function of the weld metal mechanical properties. In this case, the simple mathematical models can be used.

CONCLUSIONS

1. The presented model makes it possible to assess the effect of material discontinuities in the form of welding defects, on the durability of hardfaced elements.

2. The calculated fatigue characteristics shows some convergence with the results of fatigue tests of hardfaced samples.

3. Hardfacing of the 45 steel with the high tensile strength weld metals gives possibilities to reach the same or higher fatigue strength in comparison with base metal.

SYMBOL USED

R_m = tensile strength (MPa)

R_e = yield strength (MPa)

Z_{go} = fatigue strength (MPa)

l_o = initial length of microcrack in the material structure

l_1 = length of a crack in the surface layer

l_f = crack length assumed as a criterion of fracture

$\Delta\sigma$ = stress range (Mpa)

N_1 = number of cycles to generate the l_1 length crack in a base material, when the $\Delta\sigma$ stress is applied

N_f = durability of the base material

A,m,C,n = material constants

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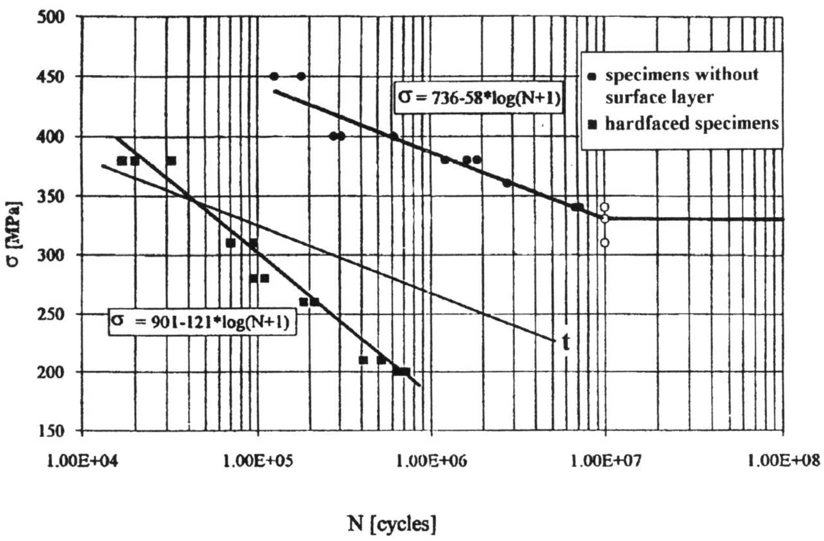

Figure 1 Fatigue diagrams (double-side bending fatigue tests)

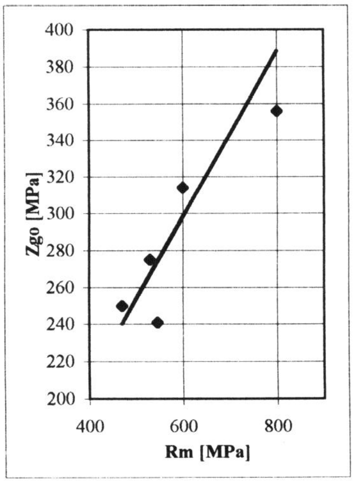

Figure 2 Relationship between tensile strength and fatigue strength

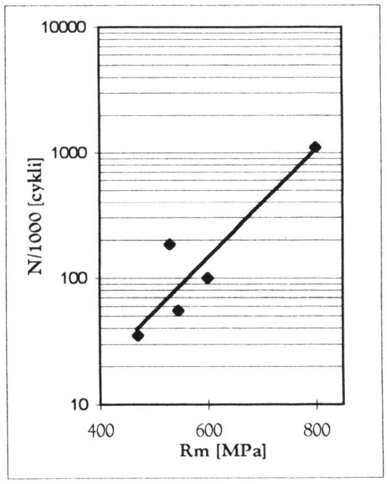

Figure 3 Relationship between tensile strength and number of cycles to failure