Influence of Corrosion through Tap Water on Fatigue Streng and Rate Fatigue Crack Propagation in Low-Carbon Steel

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1. Introduction

One of the very important factors affecting adversely the fatigue strength of structural materials is corrosion. Contrar to statically stressed structures which are disturbed due tc corrosion only after their cross-sectional area has decrease below the admissible value, the destruction of machine parts loaded with forces that vary in time due to the physical and chemical processes taking place on their surfaces /1/, which considerably impair their fatigue strength, without their cross-sectional figures having practically even changed. Und corrosion the slope of the stress-number curve changes, and the affect of stress raisers manifests itself in some other way, so that even the method of calculation /2/ has to be adjusted to cope with this fact. Of no less importance is alsc the time for which the corrosive environment acts, and so it is a matter of course that in relationships describing the mechanism of impairment due to fatigue the function of time must necessarily appear.

2. Experimental Material and Test Conditions

For the experimental process the choice was taken in favour of low-carbon steel grades comparable, according to DIN, wit St45 and St52-3, hereinafter marked as A and B, which are generally employed for welded, dynamically stressed structures such as rail- and road-bound vehicles. The former steel grad is moreover modified by an addition of aluminium to attain a higher impact strength, in particular at reduced temperatures. Their basic chemical composition is as follows:

	C	Mn	Si	P	S
Steel A	0.10	1.21	0.27	0.014	0.018
Steel B	0.18	1.32	0.42	0.016	0.019

The microstructure of the two steel grades is ferritic-to-pearlitic.

Both the steel grades of A and B mark show the same yield point of 35 kgf/sq.mm., and differ in their tensile strength in a way that for the former and the latter steel grades the tensile strength is 49 and 58 kgf/sq.mm., respectively. The effect of corrosion upon the fatigue strength was followed up on plain and notched test pieces having a theoretical stress concentration factor α_t = 2.5; 3.3, and 5.9. The test pieces were stressed by repeated flat bending with a frequency of 50 cycles/second partly in the air, partly by exposing to simultaneous corrosion through tap water.

3. Experimental Results

From the usual S-N curves displaying the dependence of fracture stresses on the number of cycles which were experimentally established during the tests in the air and under the simultaneous corrosion, the following factor can be determined:

$$\varkappa = \frac{\sigma_{om}^{\kappa}}{\sigma_{om}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where: σ_{om} ... is a stress that causes fracture at N number of cycles without any corrosion effect

σ_{om}^{k} ... is a stress that causes fracture at N number of cycles under simultaneous corrosion.

Consequently, this stress concentration factor expresses variations in the fracture stress at a particular number of cycles N_f, caused by corrosion. The variations in this factor plotted against the number of cycles for the two steel grades A and B are shown in Fig.1. It can be stated that for the plain test pieces and for test pieces with less sharp notches the value of factor $\varkappa$ is reduced as the number of cycles and so also the time of corrosion action are increased. For test pieces with sharp notches, e.g. with α_t = 5.9, the value of remains unchanged or increases but slightly, so that the effect of corrosion cannot be said to be negative from the point of view of fatigue strength. That means that the effect of simultaneous corrosion through tap water resulting in a shorter service life of machine parts will make itself felt more intensively in a case where less sharp notches are concerned. In case of parts with initial macrocracks having a high fatigue notch factor, the affect of corrosion through

tap water should, hence, not result in any reduction of their residual service life if compared with conditions prevailing in testing in the air. The relation between the fracture stresses as established on plain and notched test pieces is expressed by the so-called "fatigue notch factor β_k" which is dependent on the magnitude of the stress concentration factor α_t. How the relevant curves vary at a number of cycles N = 10^7 for tests carried out in the air and under tap water corrosion is evident from Fig.2. Whereas the curves holding good for the air are relatively steep, which means that β_k strikingly rises as α_t increases, this variation is not anyhow so marked in case of tap water corrosion as the notch sharpness is increasing, especially from α_t = 4 and on, and for these steel grades it will no doubt assume figures any greater than β_k = 1.5 to 2 under tap water corrosion. The variation in factor β_k within the range of number of cycles of stress to produce failure $N_t = 10^5 - 10^7$ is further evident from Fig.3 and indicates that for very sharp notches, and so also for initial macrocracks β_k becomes greater in the air as the number of cycles is increased. With simultaneous corrosion through tap water the value β_k undergoes then practically no changes within this range of cycles. From practical point of view that means suppressing of the influence of the sharpness of a notch upon the magnitude of factor β_k under simultaneous tap water corrosion. When formulating the regular occurrence of propagation of fatigue cracks, Paris adopted, as a ruling quantity stress intensity factor, so that the rate of crack propagation is

$$\frac{dl}{dN} = f(K) \quad \ldots\ldots\ldots\ldots (2)$$

which, expressed by Barrois, took the form of

$$\frac{dl}{dN} = A \Delta K^n \quad \ldots\ldots\ldots\ldots (3)$$

This expression can well serve the purpose of comparing various experimental results, as the constants of A and n can relatively easily be determined empirically.

As the effect of corrosion is dependent on the duration of its action or on the frequency of the alternating component of stress /3/, it is possible to write for this case the relation (3) as follows:

$$\frac{d\ell}{dN} = F(t)\Delta K^n \qquad \ldots\ldots\ldots\ldots\ldots (4)$$

The value of function F(t) then depends on the kind of material, the corrosive environment, and the frequency determining the duration of corrosion.

By plotting the length of crack l against the number of cycles N, or dl = d/f(N)/, it was possible to obtain correlation between $\frac{dl}{dN}$ and l, see Fig.4. The next Fig.No.5 shows variation of $\frac{dl}{dN}$ with the stress intensity factor ΔK. It can be stated that for both the air and the tap water the value of exponent for these two steel grades is n= 4, so that

$$\frac{d\ell}{dN} = F(t)\Delta K^4 \qquad \ldots\ldots\ldots\ldots\ldots (5)$$

In tests carried out in the air, F(t) coincides with constant A from relationship(3). With the simultaneous action of corrosion through tap water and the given frequency this value does not change to any great extent, and so there is not any significant difference in the rate of growth of the fatigue crack, either.

4. Conclusion

The effect of corrosion through tap water has made itself strongly felt in case of plain test pieces. In case of notched test pieces this effect decreased as the sharpness of the notch was increasing (Figs 1,3).

The curve showing the fatigue notch factor β_k is steep for tests carried out in the air as α_t is increasing, whereas for tests under simultaneous corrosion it is flat (Fig.2). The rate of fatigue crack propagation under corrosion has not increased to any great extent under the given conditions of testing (Figs 4 and 5).

5. Literature

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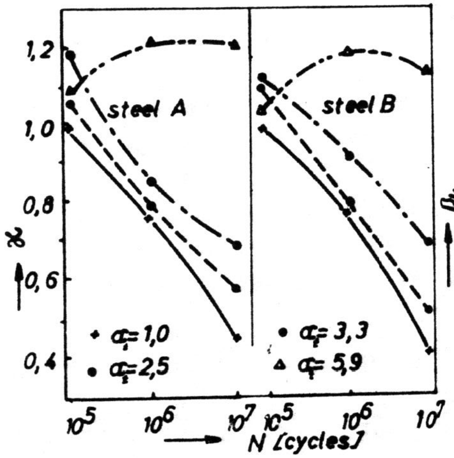

Fig. 1

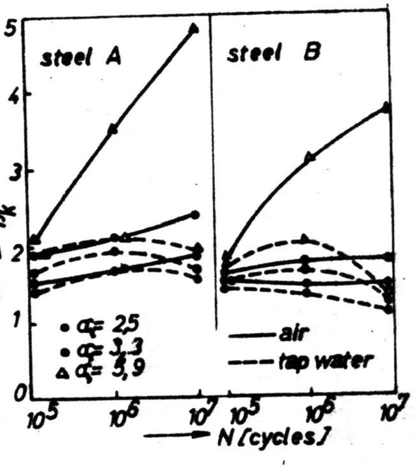

Fig. 2

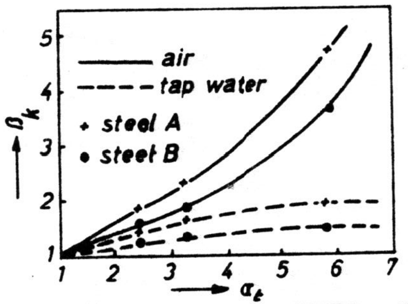

Fig. 3

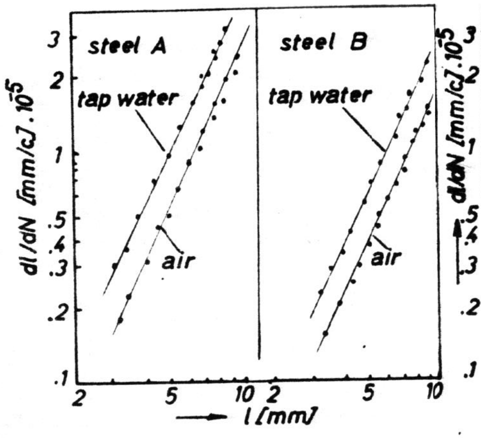

Fig. 4

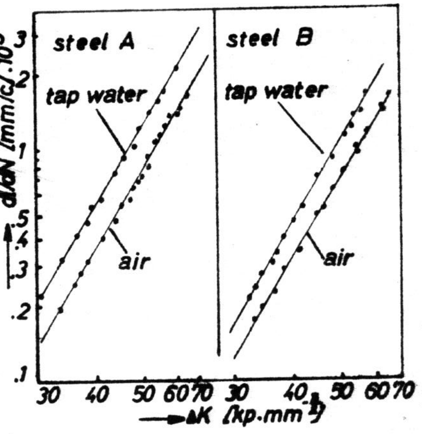

Fig. 5