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FATIGUE STRENGTH OF SINTERED STEEL DISTALOY AE WITH BORON AND CARBONYL IRON POWDER ADDITIONS

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In this paper on the fatigue strength of sintered Distaloy AE steels are presented. Specimens were prepared from diffusion alloyed Distaloy AE(Fe-4wt.-%Ni-1,5wt-%Cu-0,5wt.-%Mo)mixed with graphite (0,5wt.-%). The materials were sintered under industrial conditions at 1120 °C for 30 min. The effect of consequently on the mechanical properties was studied. The effect of the addition of different amounts of boron of 0,3 and 0,6wt.-% and carbonyl iron powder (CEP) 2,5 and 5,0wt.-% to Distaloy AE for the mechanical properties were studied.

INTRODUCTION

Fatigue strength cannot be expressed as a single valued material characteristic because it depends on many independent different and sometimes interacting parameters. In the special case of powder metallurgical parts further parameters are density, powder type, sintering temperature and time, sintering atmosphere and the effects of operations after sintering like sizing, barreling, machining, steam treatment or corrosion protection.

There are indications that also the cycling frequency can play a role if certain upper or lower limits are exceeded. Several times the published literature on fatigue of sintered metallic materials has been reviewed under various aspects [1-6]. Here, the presentation must stay restricted to endurance limits.

In general, it is assumed that iron and steel under axial, torsional or bending loading have approached a well defined endurance limit at about ten million cycles under constant amplitude testing, even though a rather unfortunate German standard (DIN 50100) permits to discontinue the test at only two million cycles already because of the tremendous times involved. The necessary testing times make fatigue testing expensive, and there have been many attempts to modify the testing procedures with limited success. Four strategies have been pursued to reduce the effort in measuring endurance limits: increased testing frequency, fewer samples, multiple sample test benches, and substituting S-N curve testing by measuring physical effects associated with the occurrence of an endurance limit. The latter approach ideally requires just a single specimen which is cycled with slowly increasing amplitude. The stress amplitude where a physical characteristic, like temperature or electrical resistivity, starts rising over the background level is anticipated the transition between long life fatigue and endurance limit. In the majority of all investigations the number of specimens has been reduced. This way the statistical significance suffers and many of the results published deserve little confidence as to the precise value of the endurable stress amplitude. In the graphical presentation of results from different sources this can be seen as a sometimes unsatisfactory scatter which does not even permit to calculate a trend curve to express the density dependence.

In accordance with the majority of all published work on fatigue of sintered iron and steel a nominal stress concept is followed here. This is to say that the loading forces and moments and the loaded cross-sections are used to calculate the nominal stresses irrespective of the specimen geometry and local stress concentrations.

The most general loading mode is axial loading which permits to vary the mean stress from negative to positive values, Fig. 1 [7].

Usually, however, the mean stress is not explicitly mentioned but indirectly expressed by the so-called stress ratio R, the ratio between minimum and maximum peak stresses. The different loading modes can be characterized by the stress ratios which can be achieved as follows:

– axial loading
$\sigma_{max} > 0 : \quad 1 < R < -\infty$
$\sigma_{max} < 0 : \quad \infty > R > 1$
– plane bending, torsion $\quad -1 \leq R < 1$
– rotating bending $\quad R = -1$
– rolling contact fatigue $\quad R = 0$

With double-logarithmic coordinates in the high cycle fatigue area, S-N curves of iron and steel can be approximated by declining straight lines which enter into the endurance limit usually before 10^7 cycles, Fig.1. Accordingly, the straight line can be mathematically described by

$$N = C\ y_a^k . \tag{1}$$

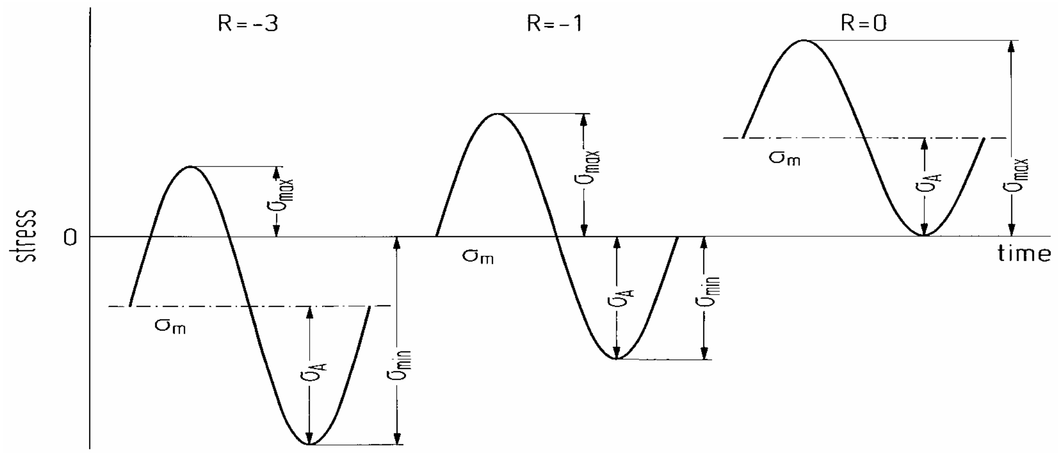

Fig. 1.
Definition of the stress ratio R.

The mean stress sensitivity characterises the drop in cyclic amplitude with increasing static mean stress. For its determination commonly two S-N curves are measured, a first one with a stress ratio R= –1 and a second one with a stress ratio of R = 0, where R is the ratio of minimum and maximum stress within a full loading cycle, Fig.1:

$$R = \frac{y_{min}}{y_{max}} = \frac{y_m - y_a}{y_m + y_a} \tag{2}$$

with σ_m and σ_a: mean static stress and stress amplitude, respectively.

In [8] it is estimated that rotating bending delivers typically about 20% higher endurance limits than comparable tests with as sintered surfaces. Since, however, the surface modification by machining is not too well reproducible, rotating bending results predominantly contribute to the experimental scatter. Also when testing notched geometries, the endurance limits with machined notches were in general significantly higher than with pressed and sintered notches of identical geometry, yet, the results depended very much on details of the machining conditions and could not be reliably reproduced [9, 10]. Too few results from torsion testing are available for a comparison, the effects should be similar to those from rotating bending.

Many results have been published over and over again on different occasions. Over the years sometimes the original experimental results have been adjusted by the authors to fit into a certain frame. In these cases, as far as accessible, the first publications or the original research reports were preferred for the evaluation over later versions, which often do not contain the measured data any more. Where absolutely necessary the original S-N curves were reevaluated with respect to endurance limit for reasons of consistency.

EXPERIMENTAL AND RESULTS

Fatigue tests with stress levels above the endurance limit have been carried out the determine Woehler curves. The obtained curves for the different series of samples are shown in Fig.2. and Fig.3. and include the fatigue limits at 5, 10, 50, 90 and 95 probability of survival. The points in the diagrams correspond to the raw data, each open circle indicates a failure and each filled circle a run out.

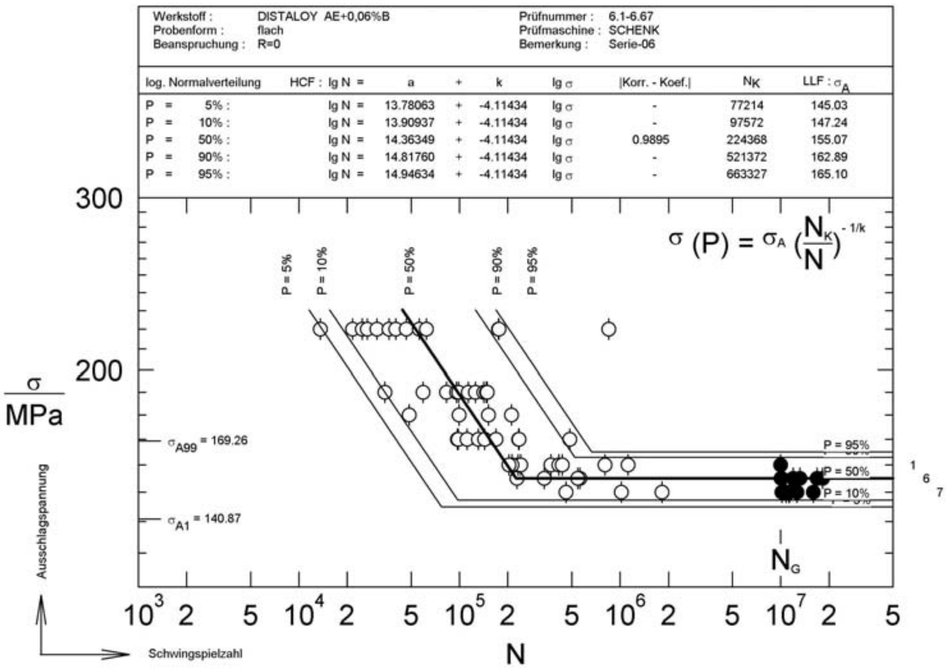

Fig. 2.

Fatigue endurance limit and probability of survival of the material Distaloy AE+0,06%B.

For the higher strength range samples were manufactured from the widely used Distaloy family of steels containing 4% Ni, 1.5% Cu and 0.5% Mo which are diffusion bonded to pure iron to prevent segregations and maintain highest compressibilities. All powders were blended with 0.5 fine graphite and in most cases with additions, which were expected to change the pore morphology. As additions carbonyl iron powder (CEP) and boron were used. Further the standard grade, Distaloy AE, based on water atomised iron was made from a coarse powder >45µm and a fine fraction <45µm and compared with the same alloy based on sponge iron. The specimens were compacted with 600MPa in the R & D department of Höganäs AB, Sweden, were the sintering took place in semiindustrial equipment at 1120°C in a non-decarburizing protective atmosphere. The cooling rate between 800 and 500°C was 1.0°C/s. Details on the as-sintered densities and some mechanical properties are provided in Table 1.

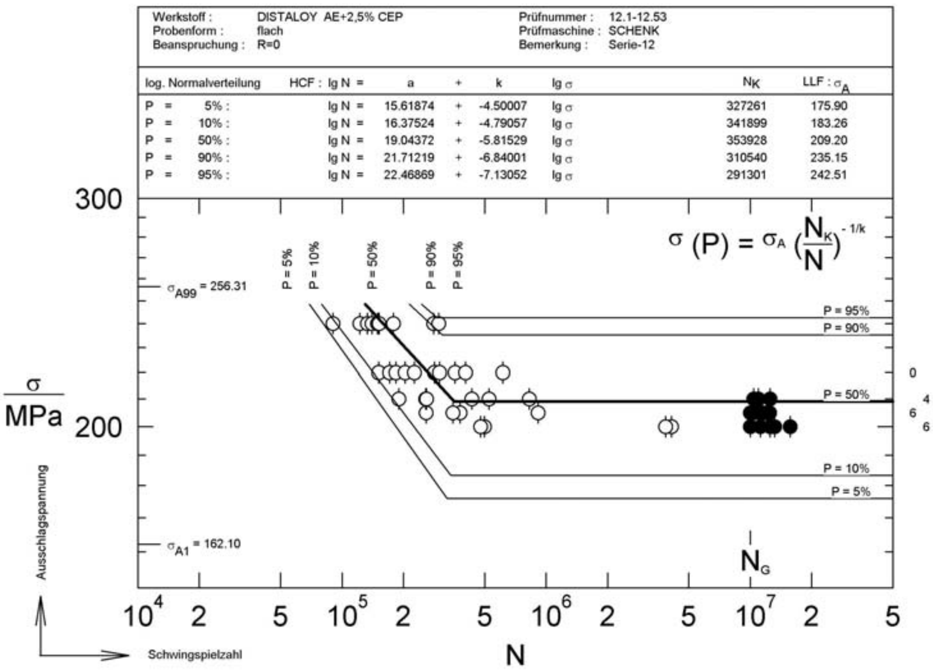

Fig. 3.

Fatigue endurance limit and probability of survival of the material Distaloy AE+2,5%CEP.

Plane bending fatigue tests were performed with 60 specimens in six stress levels per S-N curve, which permits to evaluate the data statistically and to determine a rather reliable endurance limit for a failure of survival probability of 50%.

Table 1.

Materials investigated, 4% Ni, 1.5% Cu, 0.5% Mo, 0.5% C

Base powder	Addition, modification	Density, average g/cm^3	Hardness HV 10	$R_{p0.2}$ MPa	R_m MPa
DistaloyAE	2.5%CEP	7.003	250	429	723
DistaloyAE	5.0%CEP	7.006	229	432	712
DistaloyAE	0.03 % B	6.997	232	386	617
DistaloyAE	0.06 % B	7.023	202	356	531

Plane bending fatigue tests were performed with 60 specimens in six stress levels per S-N curve, which permits to evaluate the data statistically and to determine a rather reliable endurance limit for a failure of survival probability of 50 %. Half the tests were made with a stress ratio of R=–1, the other half were made with R=0. Loading was discontinued at 10^7 cycles. The endurance limits obtained for 50% survival probability are listed in Table 2.

Table 2.
Endurance limits at 10^7 cycles at 50 % survival probability.

Material	Endurance limit	
	R = – 1 MPa	R = 0 MPa
D. AE + 2.5 % CEP	242	206
D. AE + 5.0 % CEP	235	192
D. AE + 0.03 % B	235	173
D. AE + 0.06 % B	205	154

The ratio of the endurance limits at 10 and 90 % survival probability was 1.125 as an average from the 24 S-N curves obtained in this study, as opposed to a value of 1.25 which is often quoted for sintered iron and steel. This difference can be attributed to the greater experimental effort to generate the data in the present work

The dependence fatigue endurance of probability of survival of the material Distaloy AE+0,06%B and of the material Distaloy AE+2,5%CEP are shown in Fig.4. and in Fig.5.

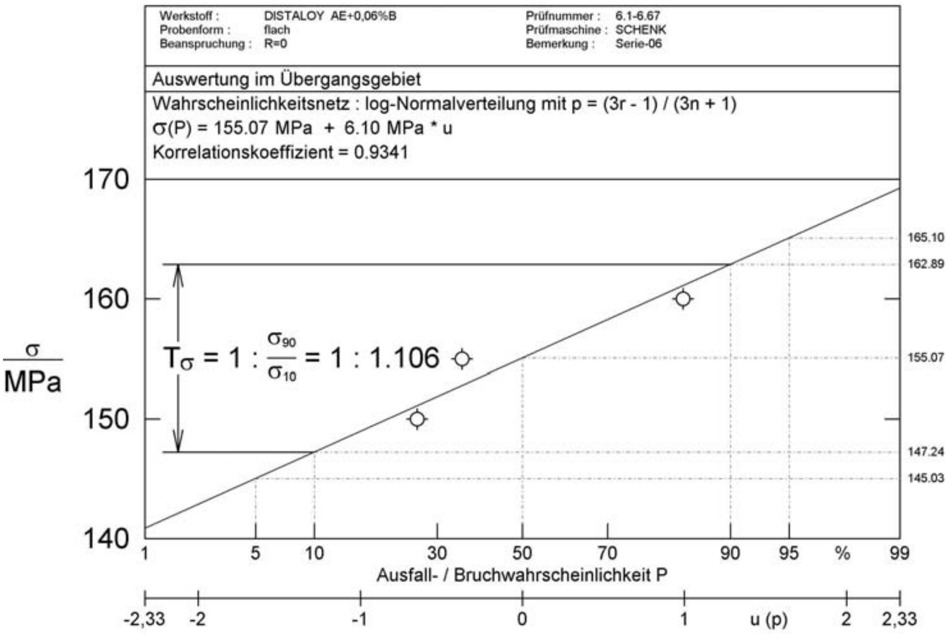

Fig. 4.
Dependence fatigue endurance of probability of survival of the material Distaloy AE+0,06%B.

The dependence number of cycles of probability of survival of the material Distaloy AE+0,06 % B and of the material Distaloy AE+2,5 % CEP are shown in Fig.6. and in Fig.7.

SUMMARY

Fatigue tests with stress levels above the endurance limit have been carried out to determine Woehler curves. The effect of consequently on the mechanical properties was studied. The effect of the addition of different amounts of boron of 0,3 and 0,6wt.-% and carbonyl iron powder (CEP) 2,5 and 5,0wt.-% to Distaloy AE for the mechanical properties were studied. The fatigue limit at 50 % probability of survival was for the material Distaloy AE +0,06%B 155,7MPa, the korrelationkoeffizient 0,934 and for material Distaloy AE+2,5%CEP 209,2MPa, korrelationkoeffizient 0,866.

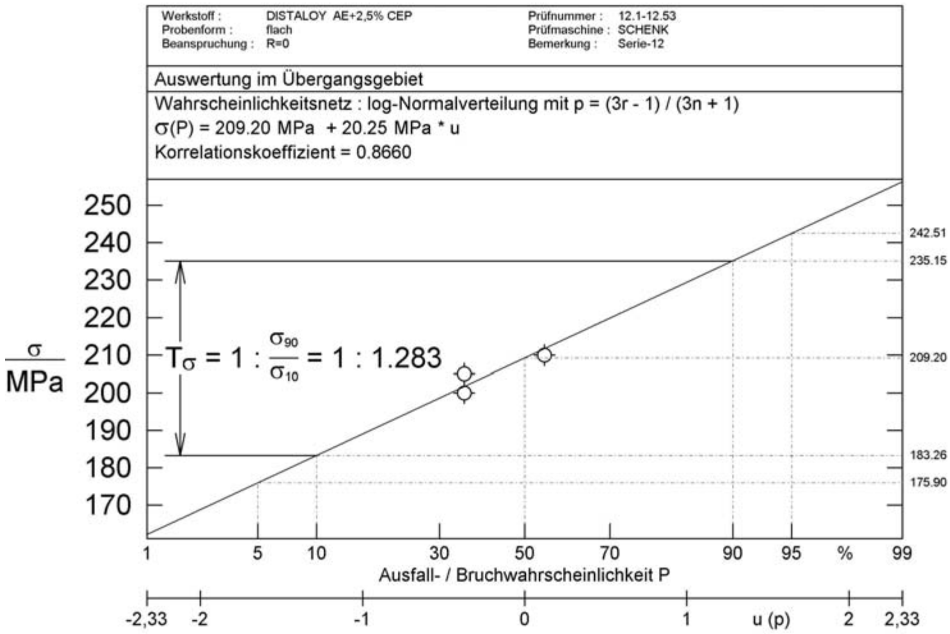

Fig. 5.

Dependence fatigue endurance of probability of survival of the material Distaloy AE+2,5%CEP.

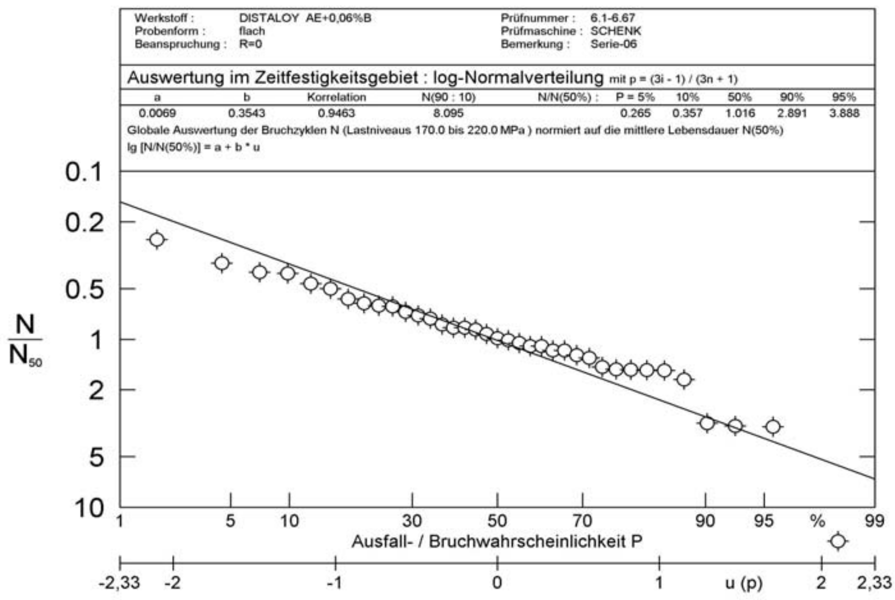

Fig.6.

Dependence number of cycles of probability of survival of the material Distaloy AE+0,06%B.

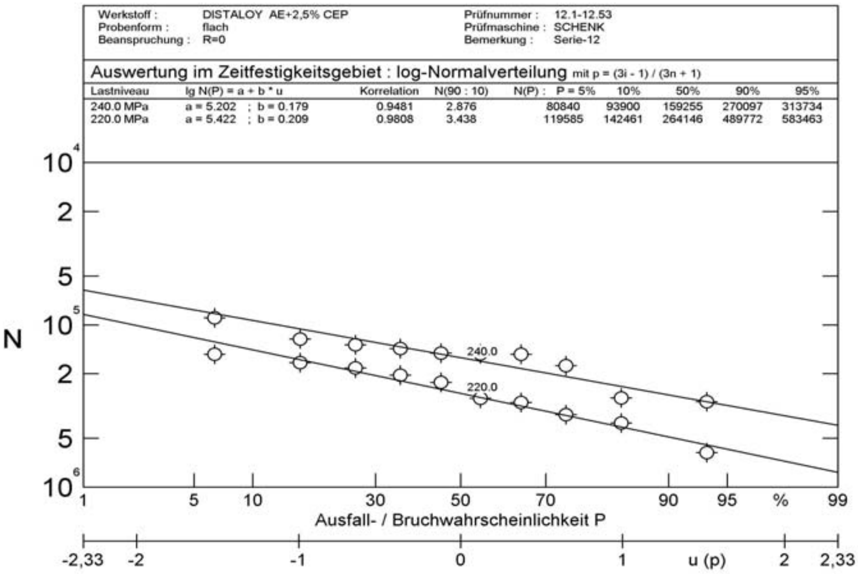

Fig. 7.

Dependence number of cycles of probability of survival of the material Distaloy AE+2,5%CEP.

Evaluating a larger group of data on the endurance limit of sintered steel, it is shown that the ratio of pulsating to alternating endurance stress amplitude obeys an equation derived from the above reasoning.

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BOR VƏ KARBONİL DƏMİR OVUNTUSU İLƏ LEQİRLƏNMİŞ DİTALOY AE ƏSASLI BİŞİRİLMİŞ OVUNTU POLADLARININ YORULMADA MÖHKƏMLİK XARAKTERİSTİKALARI

S.N.NAMAZOV

Məqalədə Distaloy AE əsaslı bişirilmiş ovuntu poladlarının yorulmada möhkəmlik xarakteristikaları tədqiq edilmişdir. Bu məqsədlə Distaloy AE markalı (Fe -4 küt.%Ni -1,5küt.% Cu -0,5küt.%Mo) ovuntu poladı qrafitlə (0,5küt.%), müxtəlif miqdarda bor ovuntusu (0,03 və 0,06küt.%) və karbonil dəmir ovuntusu (2,5 və 5,0küt.%) ilə qarışdıralaraq nümunələr hazırlanmışdır. Bişirmə sənaye şəraitində 1120°C temperaturda 30 dəq. müddətində yerinə yetirilmişdir. Alınmış materialların mexaniki xassələri – yorulmada möhkəmlik xarakteristikaları tədqiq edilmişdir. Həmçinin bor (0,03 və 0,06küt.%) və karbonil dəmir (2,5 və 5,0küt.%) ovuntusunun mexaniki xassələrə təsiri öyrənilmişdir.

УСТАЛОСТНАЯ ПРОЧНОСТЬ СПЕЧЕННЫХ ПОРОШКОВЫХ СТАЛЕЙ С ДОБАВЛЕНИЯМИ БОРНОГО ПОРОШКА И ПОРОШКА КАРБОНИЛЬНОГО ЖЕЛЕЗА

С. Н. НАМАЗОВ

В этой статье представлены усталостные прочностные характеристики спеченных порошковых сталей на основе Distaloy AE. С этой целью были подготовлены образцы широко распространенных порошковых сталей Distaloy AE (Fe-4мас.%Ni-1,5мас.%Cu-0,5мас.%Mo) путем смешивания с графитом (0,5С%) борного порошка и порошка карбонильного железа. Спекание материалов проводилось в индустриальных условиях при 1120°С в течение 30 мин. Изучены механические свойства полученных материалов. Одновременно изучено влияние легирующих элементов на механические свойства сталей в случае различных количеств борного порошка 0,03 и 0,06мас.% и порошка карбонильного железа (CEP) 2,5 и 5,0мас.%С Distaloy AE.

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