Paper No.
62—WA-164

Fatigue Characteristics of Open-End Thick-Walled Cylinders Under Cyclic Internal Pressure

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Thick-walled cylinder fatigue data due to cyclic internal pressure for open-end cylinders in the range of 10^3 to 10^5 cycles to failure and having a diameter ratio of 1.4 to 2.0 at a nominal yield strength of 160,000 pounds per square inch is presented. Discussed and also presented are the effects of autofrettage on the fatigue characteristics of thick-walled cylinders. Autofrettage substantially enhances fatigue characteristics at stress levels below the corresponding overstrain pressure, the degree of improvement increasing the decreasing stress levels. The rate of improvement in fatigue characteristics increases significantly with diameter ratio in autofrettaged cylinders up to a diameter ratio of 1.8–2.0 and to a much smaller degree in the nonautofrettaged condition. The rate of improvement of fatigue characteristics above 2.0 is the same for both the autofrettaged and nonautofrettaged cases.

It is shown that thermal treatment of 675 F for 6 hours after autofrettage does not affect fatigue characteristics and that there is a correlation between the cyclic-stress level and the area and depth of the fatigue crack to the point of ductile rupture. The depth of the fatigue crack decreases with increasing cyclic-stress level.

A means for using data from a unidirectional tensile fatigue test to predict the fatigue characteristics of thick-walled cylinders is discussed.

Introduction

The current trend is toward the design of pressure vessels for use at higher operating stress levels. One of the most common techniques for extending the elastic load-carrying capacity is by autofrettage. For example, the operating pressure-to-weight ratio for cannon-type weapons has been substantially increased in recent years by the combined use of high-strength materials and autofrettage. Similar advances have been made in other areas where the requirement exists for vessels capable of operating at very high pressures.

In many instances, the operation of highly stressed pressure vessels is cyclic in nature. In these instances, it is not enough to consider the yielding characteristics alone, but one must also take into account the problem of fatigue life and the manner in which it is affected by such techniques as autofrettage for increasing elastic load-carrying capacity. This report summarizes the results of an experimental program aimed at the study of the fatigue characteristics of high-strength open-end cylinders of intermediate diameter ratio.

The fatigue characteristics of a closed-end cylinder cyclically stressed in the region of the endurance limit have been reported by Morrison, et al. [1].[1] He has found that, in the region of the endurance limit, the residual stresses associated with overstrain substantially enhance fatigue life. Similar results were found by Newhall and Kosting [2] for several rifled sections of cannon tubes, at somewhat higher stress levels.

In light of the current interest in the use of highly stressed pressure vessels, the investigation to be described herein involves a study of fatigue characteristics of thick-walled cylinders in what is commonly referred to as the low-cycle fatigue range, that is up to approximately 10^5 cycles to failure. Presented are data for open-end cylinders in the diameter-ratio range of 1.4 to 2.0 at a nominal yield-strength level of 160,000 pounds per square inch. Data are also presented on the effects of autofrettage on fatigue characteristics as a function of diameter ratio and cyclic stress level. The possibility of utilizing a simple tensile fatigue test to

Contributed by the Metals Engineering Division for presentation at the Winter Annual Meeting, New York, N. Y., November 25–30, 1962, of The American Society of Mechanical Engineers. Manuscript received at ASME Headquarters, August 6, 1962. Paper No. 62—WA-164.

[1] Numbers in brackets designate References at end of paper.

Nomenclature

σ = stress, pounds per square inch
YS = yield strength, pounds per square inch
UTS = ultimate tensile strength, pounds per square inch
E = modulus of elasticity, pounds per square inch
ν = Poisson's ratio
P = test pressure, pounds per square inch
b = outside diameter of cylinder, in.
a = inside diameter of cylinder, in.
W = wall ratio b/a
NA = nonautofrettaged
A = autofrettaged
D = ratio of lower limit of a confidence level to least-squares value
N = cycles to failure
R = radius of elastic-plastic interface, in.
t = confidence-level coefficient
S = standard deviation
x = logarithm to base 10 of cycles to failure
n = number of experimental points
d = depth of crack, in.
r = correlation coefficient
w = wall thickness, in.

Subscripts

$(\ )_t$ = tangential
$(\ )_r$ = radial
$(\ )_z$ = longitudinal
$(\ )_y$ = yield
$(\ )_p$ = plastic
$(\ )_{trp}$ = tangential residual plastic
$(\ )_{rrp}$ = radial residual plastic
$(\ )_c$ = confidence level
$(\bar{\ })$ = least squares value of function

Discussion on this paper will be accepted at ASME Headquarters until January 10, 1963

predict the life of thick-walled cylinders, and the mode of fatigue fracture for cylinders exposed to cyclic internal pressures is discussed.

Procedure

Test Specimens. The specimens utilized in this program consisted of a common one-inch internal diameter and diameter ratios of 1.4, 1.6, 1.8, and 2.0.

The specimen material was of a 4340-type composition with the following nominal chemical analysis in percent:

Carbon	0.37	Nickel	2.39
Manganese	0.72	Chromium	0.98
Silicon	0.28	Molybdenum	0.38
Sulfur	0.035	Phosphorus	0.016

Specimens were heat-treated to a nominal yield strength of 160,000 pounds per square inch by austenizing at 1525 F, oil quenching, and tempering at 1075 F ± 25 deg. Tensile and Charpy test specimens were taken from each group of three specimens which were heat-treated in 40-inch lengths.

After heat-treatment, sufficient material was removed from the bore to eliminate any decarburization. The final surface finish on the internal diameter ranged from 16 to 125 RMS.

The autofrettaged specimens were overstrained 100 percent in the manner described in reference [3]. Those specimens that were thermally treated after autofrettage to reduce anelastic effects were subjected to a temperature of 675 F for 6 hours.

Test Apparatus. The pressure systems used in this program consisted of two basic types. The first is a Harwood Engineering Company System of 80,000 pounds per square inch capacity with a cyclic rate of up to 20 cycles/minute. As shown in the background of Fig. 1, the pressure source consists of an intensifier-type pump which feeds high-pressure fluid into the specimens through a manifold. As can be noted from the figure, four specimens may be tested simultaneously. The holding press serves to support the pressure packings which effectively eliminates longitudinal forces in the specimen, thus resulting in the open-end condition for the specimens. Upon attaining the peak pressure, a valve is opened and the pressure dropped to near atmospheric level. The high-pressure fluid is an instrument oil. A schematic of this system is shown in Fig. 2.

The second type is a Harwood Engineering Company System of 150,000 pounds per square inch capacity with a cyclic rate of up to 10 cycles/minute and consists of an intensifier-type pumping system which feeds pressure into the specimens. In contrast to the former system, the pressure is released by removing the drive pressure in the intensifier instead of venting to atmosphere: thus resulting in a closed system. This results in the pressure not returning to zero between cycles, but to a value of approximately 2500 pounds per square inch. However, since this system is used primarily above 80,000 pounds per square inch, a small residual pressure will have little effect, and the comparative results from both systems are in the range of anticipated experimental error.

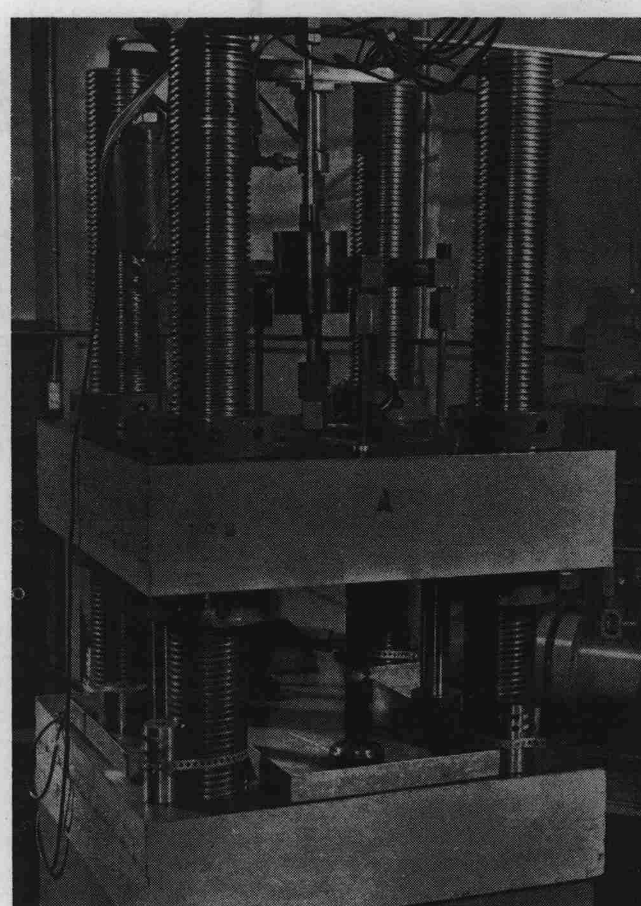

Fig. 1 Holding press and specimens for 80,000 pounds per square inch fatigue system

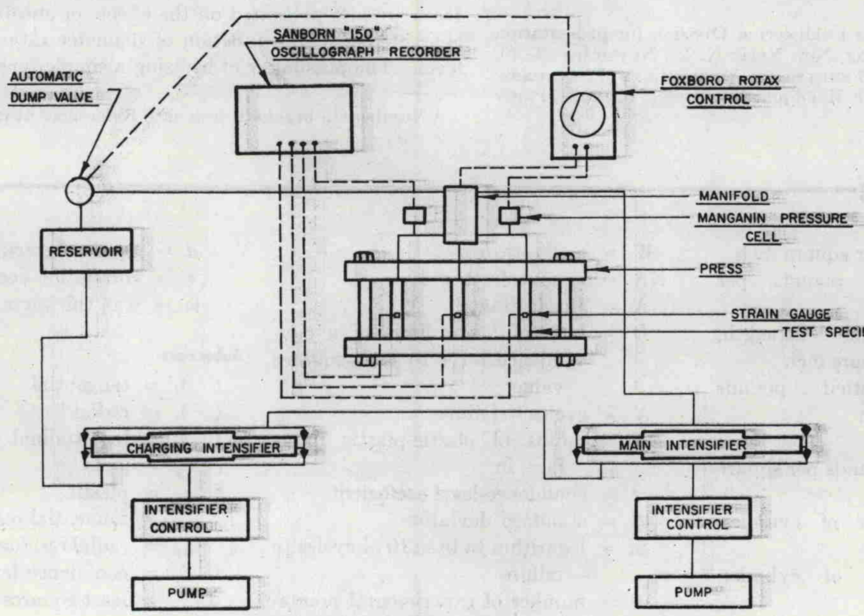

Fig. 2 Schematic of the 80,000 pounds per square inch fatigue system