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ROTATING BENDING FATIGUE TESTS ON 17.7PH-RH950

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Acknowledgement/Preface
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Abstract
For the application of 17.7PH-RH950 steel as a replacement for MP35N, the fatigue strength needs to be determined. Currently, MP35N is used for the construction of the Vortex Finder of Twister. In this application, the construction is submitted to a high frequently fatigue load. This means that the fatigue strength at an unlimited number of cycles needs to be known. The unlimited number is set at 10^8 cycles for this investigation.

The fatigue strength of 17.7PH-RH950 was determined in a rotating bending beam test. Because of the limited material plate thickness, the sample size was adjusted. For comparison, also a limited number of tests using MP35N with the same sample geometry were performed.

In the rotating beam bending test, fatigue strengths for MP35N were in line with supplied fatigue strengths by the supplier of the material. For 17.7PH-RH950, the fatigue strength for 10^8 cycles was determined to be 600 MPa. This fatigue strength is comparable to that of MP35N.

Keywords
MP35N, 17.7PH-RH950, rotating beam testing, fatigue, metallography, Wöhler curve.

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SUMMARY

Rotating beam fatigue tests were performed on 17.7PH-RH950. A Wöhler curve was determined and the results were compared to the cobalt base alloy MP35N with tensile strength of 1925 MPa. The rotating fatigue tests were performed on a Schenck-rotating beam fatigue machine. The test samples dimensions had to be adapted to comply with the test material plate thickness of 6 mm.

A Wöhler curve was successfully constructed for the 17.7PH-RH950 material. Fatigue behaviour parallel and perpendicular to the rolling direction were comparable. The fatigue strength at 10^8 cycles is 600 MPa. The orientation of the test samples was checked metallographically after the test.

1. INTRODUCTION

STORK-SPE intends to replace part of the Vortex Finder, currently made out of the cobalt base alloy MP35N, by the precipitation hardening stainless steel 17.7PH-RH950. Before this substitution can be implemented, the fatigue behaviour of 17.7PH-RH950 needs to be determined since only little is known in literature on fatigue data concerning this material. The supplier, Carpenter, presents fatigue data of MP35N. These data were obtained using rotating beam fatigue tests.

ECN-Technology Services & Consultancy (TS&C) - Materials Technology was asked to construct a Wöhler curve for the 17.7PH-RH950 material in both the rolling direction and perpendicular to the rolling direction. For comparison reasons also fatigue tests on MP35N will be performed in the same set up. As a result a table with fatigue data on 17.7PH-RH950 and a Wöhler curve will be presented. The fatigue strength at 10^8 cycles will be determined.

2. TEST SET UP AND MATERIALS

2.1 Test set up

Testing machine

The rotating beam fatigue tests were performed using a Schenck rotating-beam fatigue machine type PUP-N, see Figure 2.1. For the test the following technical data are of interest:

- Bending load: max 900 MPa,
- Rotating speed: 2800 RPM

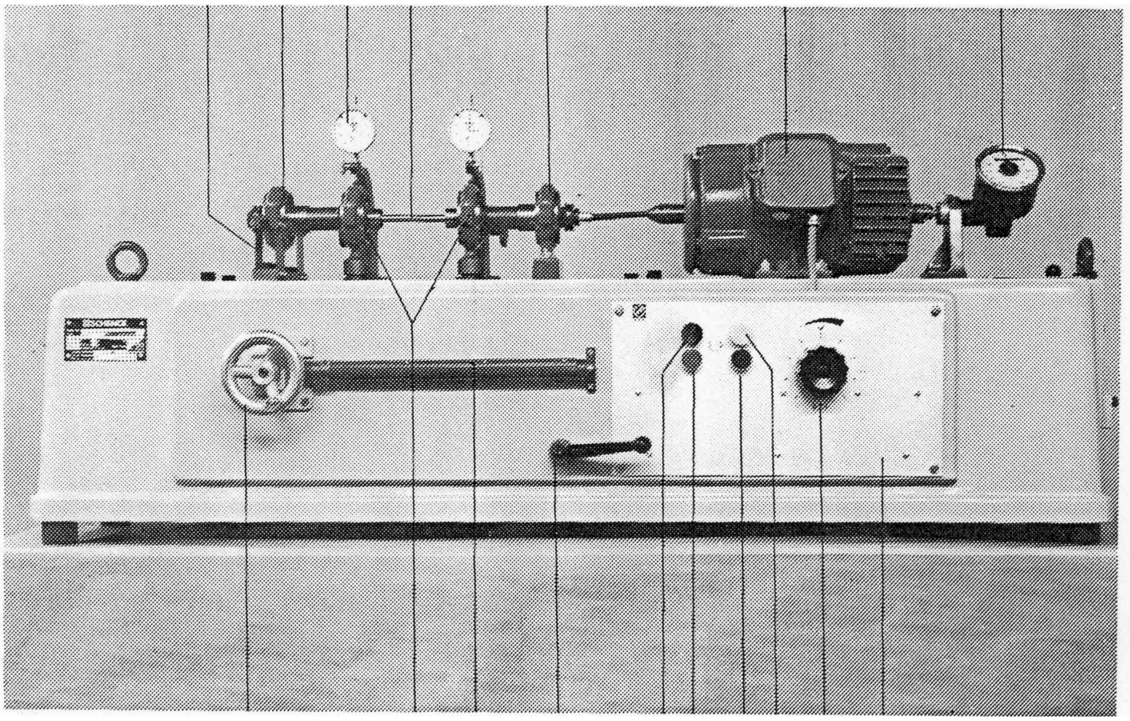


Figure 2.1 *Schenck rotating beam test machine type PUP-N*

Test samples

As a standard, the testing machine is designed to operate using two types of test samples:

1. A standardised test sample with a length of 226 mm, a testing length of 96 mm and a minimum diameter of 7.52 mm.
2. Small sized test samples with a length of 40 mm, a diameter at the clamping position of 8 mm and in the testing area of 5 mm with a radius of R=19 mm, as shown in Figure 2.2.

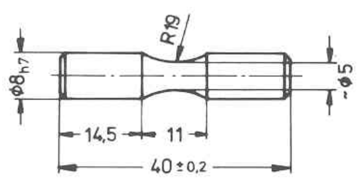
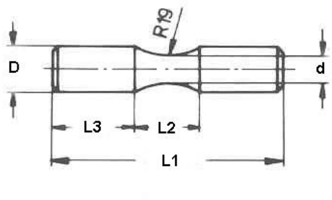


Figure 2.2 *Standard small sized test sample*

In the case of the 17.7PH-RH950 material to be tested however, the plate material available had a thickness of only 6 mm. Because of this limitation, the sample size needed to be adjusted, see Figure 2.3. A new tool had to be made to mount the samples in the testing machine. Comparing the obtained test results for MP35N with known fatigue data is used as validation for the smaller test sample.



D [mm]	d [mm]	R [mm]	L1 [mm]	L2 [mm]	L3 [mm]
6	3	19	40	15	12.5

Figure 2.3 *Dimensions of the test samples used for both 17.7PH-RH950 and MP35N*

Test loads

For 17.7PH-RH950, the bending load was varied between 600 and 900 MPa.

MP35N was tested using a bending load of 682 and 600 MPa. From fatigue data presented in the literature the former load is known to be the fatigue strength at 10^7 cycles for the cold drawn and aged to 1827 MPa strength level condition (see Table 2.1).

2.2 Materials

Three test plates of material were supplied by STORK-SPE:

- Two plates of 17.7PH-RH950. One taken in the rolling direction and one taken perpendicular to the rolling direction.
- One remnant of Carpenter-MP35N (Cold drawn and aged to 1827 MPa strength level) for reference. The tensile strength of the delivered MP35N-material was determined by STORK-SPE at 1925 MPa. Fatigue data supplied by the supplier are given in Table 2.1.

Table 2.1 *Room temperature R.R. Moore Bending Fatigue Strength for Carpenter MP35N Alloy*

	Stress (MPa) for cycles to Failure		
Condition	10^6	10^7	10^8
Cold drawn and Aged to 1517 MPa Strength level	689	620	606
Cold drawn and Aged to 1827 MPa Strength level	744	682	668

Fifteen test samples of 17.7PH-RH950 and two test samples of MP35N were manufactured according to Figure 2.3. The surface roughness (Ra value) and the smallest diameter were measured on all samples. The surface roughness is one of the main parameters determining the fatigue strength. One sample (#15) of the 17.7PH-RH950 shows a relatively large deviation from the set dimensions. This sample was set aside and was kept out of the test. The determined surface roughness and dimensions are given in Table 3.1 (Chapter Results).

Metallographic investigation on the sample orientation

The orientation of the test samples with respect to the rolling direction was checked metallographically. Cross sections were cut perpendicular to the sample's length and prepared for all tested samples of 17.7PH-RH950. Figure 2.4 shows a schematic presentation of the observed microstructure in relation to the sample orientation and the rolling direction.

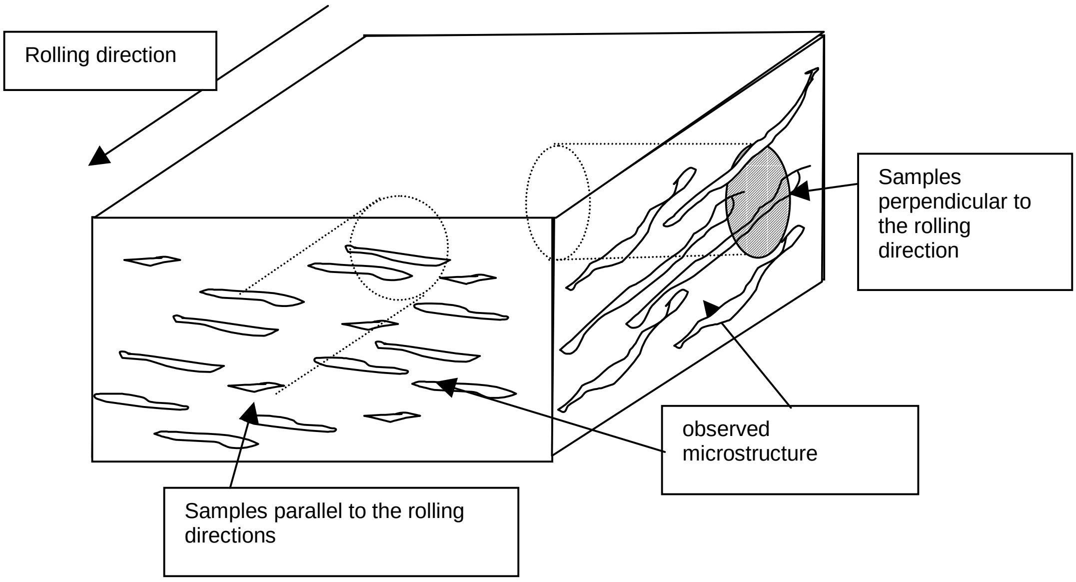


Figure 2.4 *Sectioning of the samples for metallographic examination with respect to the rolling direction*

3. RESULTS

3.1 Rotating beam tests

The test results are presented in Table 3.1 and graphically presented in Figure 3.1.

Table 3.1 *Rotating beam fatigue test results and sample dimensions*

Sample #	Roughness Ra	d [mm]	orientation with respect to rolling direction	number of cycles	load [MPa]	remarks
17-7PH-RH950						
1	0.91	3.005	parallel	8.47E+05	800	
4	1.12	2.989	parallel	5.43E+07	600	
6	0.86	2.999	parallel	1.11E+05	900	
8	0.96	3.003	parallel	1.01E+05	850	
9	0.96	3.000	parallel	7.96E+04	850	
11	0.89	3.005	parallel	3.62E+05	750	
13	0.88	3.004	parallel	1.30E+08	650	SAMPLE NOT BROKEN. Test terminated
2	0.56	3.004	perpendicular	2.17E+05	800	
3	0.37	2.994	perpendicular	9.59E+05	700	
5	0.51	2.986	perpendicular	1.28E+08	650	SAMPLE NOT BROKEN. Test terminated
7	0.84	3.007	perpendicular	9.68E+04	900	
10	0.65	3.001	perpendicular	1.44E+05	800	
12	0.43	2.989	perpendicular	1.30E+08	600	Failed after malfunction of a bearing
14	0.74	3.005				Not tested
15	0.48	2.976				Not tested (wrong dimensions)
MP35N (1925 MPa)						
21	0.32	3.014	not determined	3.40E+07	682	
22	0.35	3.012	not determined	1.50E+08	600	SAMPLE NOT BROKEN. Test terminated

MP35N

Failure of MP35N reference material occurs after $3.4*10^7$ cycles at 682 MPa. This is in agreement with the known material data for failure after 10^7 cycles.

The sample of MP35N tested with a load of 600 MPa is still intact after $1.5*10^8$ cycles. The test was terminated. Although only a limited of number of test was performed on MP35N, it is concluded that the results are in line with the fatigue data supplied by Carpenter, Table 2.1. From these results it is concluded that the use of smaller test samples is valid.

17.7PH-RH950

For two samples tested at 650 MPa, taken parallel and perpendicular to the rolling direction, the test was terminated after $1.3*10^8$ cycles. The samples did not fail. Of the samples tested at 600 MPa, one sample (#4) taken parallel to the rolling direction failed after $5.4*10^7$ cycles. The apparent premature failure of this sample is most likely caused by the relatively high surface roughness (Ra = 1.12 µm), against the overall roughness of the other samples of Ra ≤ 0.9 µm. The other sample (#12), taken perpendicular to the rolling direction, failed after $1.3*10^8$ cycles. A malfunctioning bearing may have played a role in this failure.

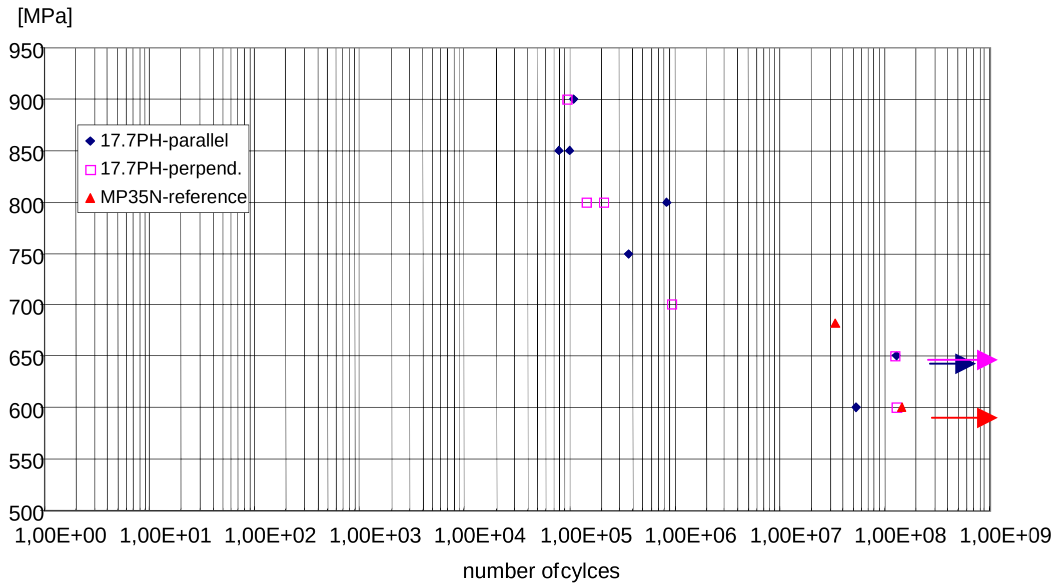
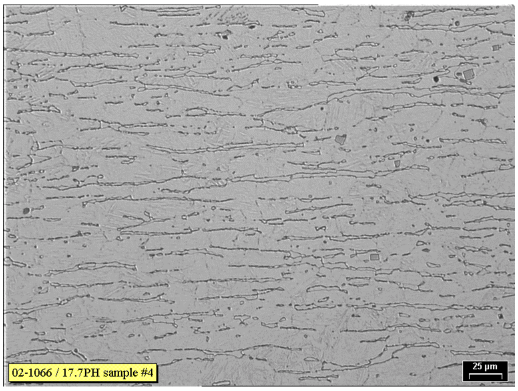


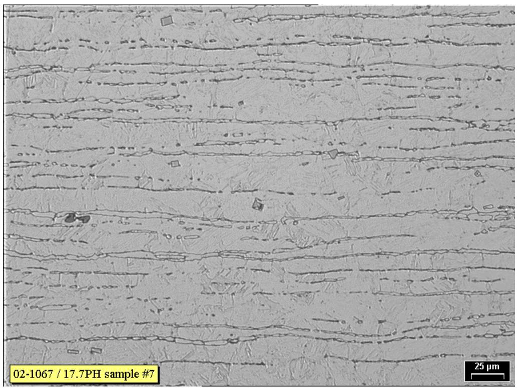
Figure 3.1 *Wöhler curve of 17.7PH-RH950. The results of the MP35N reference samples are presented separately in this curve*

3.2 Metallographic examination

Cross sections were prepared and metallographically examined for all tested 17.7PH-RH950 samples. The orientation with respect to the rolling direction was determined using the δ-ferrite bands. The two possible microstructures are presented in Figure 3.2.



(a) Plane perpendicular to the rolling direction, sample taken parallel to the rolling direction



(b) Plane parallel to the rolling direction, sample taken perpendicular to the rolling direction

Figure 3.2 *Microstructures of 17.7PH-RH950. V2A-etch*

4. CONCLUSIONS

- A Wöhler curve was determined for 17.7PH-RH950 using rotating beam fatigue testing.
- The use of smaller test samples for the determination of the Wöhler curve was validated.
- The fatigue strength of 17.7PH-RH950 at 10^8 cycles was determined to be 600 MPa.
- The fatigue behaviour of 17.7PH-RH950 was comparable for the samples taken parallel and perpendicular to the rolling direction.
- For MP35N the determined number of cycles of $3.4*10^7$ to failure at a load of 682 MPa, is in agreement with the data supplied by Carpenter, stating 10^7 cycles at 682 MPa to failure.