# FATIGUE TESTING OF MINIATURE TEST SPECIMENS AND CORRELATION OF THE RESULTS WITH THE STANDARD TEST SPECIMENS

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**Abstract**

This paper deals with the correlation of the fatigue tests results obtained on standard and miniature test samples. The aim was to compare the fatigue properties (Wöhler curves) of the samples of 15CH2NMFA steel of different cut off CT/50 test specimens after fracture toughness tests. The advantage of the use of these miniature samples is the minimum volume of removed material necessary for the production of test samples. This makes it possible to check the components in service, e.g. pressure vessels, steam turbine casings and rotors, steam pipelines, and other components of power plants after some time of operation in order that the residual lifetime could be determined. The article discusses the design of tests samples and clamping fixtures, test conditions and resulting correlation of test results.

**Keywords:** Small fatigue test, SFT specimens, Miniature fatigue testing, Small punch testing, 15CH2NMFA

## 1. INTRODUCTION

There are systems which are used continuously. Defects of some parts of the system can cause fatal accidents. Fatigue is the weakening of a material caused by repeatedly applied loads. There are many reasons why fatigue testing of these parts can be very problematic e.g. size or shape of the test specimen for fatigue testing, direction of loading, require to shutdown, etc. At present, a great interest is given to the testing of miniature specimens. The biggest advantage is the almost non-destructive intervention into the integrity of mechanical components thanks to the small amount of the removed material. This semi-destructive method makes it possible to evaluate the current status of operating components on small samples which do not disrupt the integrity of the operating components and makes it also possible to evaluate the current status without long outages. Testing of miniature specimens followed by correlation of the results with standard samples should help to determinate fatigue limit on parts, which cannot be checked. There are also possibilities of testing local fatigue properties of components, therefore it can be utilize for inspection of welds, where can be measured fatigue properties of heat-affected area. This problematic is very comprehensive and requires more experiments for better understanding.

## 2. THE EXPERIMENTAL MATERIAL

The experimental material considered in this paper is the 15Ch2NMFA steel. It is a low-alloy Chromium - Nickel steel used in the past for the production of nuclear pressure vessels of VVER type. Three different melts of this steel, designated HB, SB and PL were used for the test specimen manufacturing. Control tests of chemical composition (tested on SPECTRO, Spectrolab LAX X7) and metallographic examination (tested on metallography microscope Nikon Epiphote 300) proved the type of the steel and its bainitic structure. Mechanical tests confirmed the ultimate tensile strength of 690 MPa (tested on Zwick Roell Z250). During the realized fatigue tests, standard and miniature test specimen results were compared [1].

## 3. TEST SPECIMEN FOR FATIGUE TESTING

### 3.1. Standard test specimens

Two types of standard test specimens were used for the fatigue testing: the first specimen type was a test bar in accordance with the CSN EN ISO 420363, see **Figure 1**.

These specimens were tested at the Research and Testing Institute Plzen (VZU) in tension with the stress cycle asymmetry R = 0.1[2].

The second type of standard test specimens was produced as a prismatic bar and fatigue tested at VUT Brno in bending, cycle test asymmetry was R = 0 and R = =1 respectively.

The test specimens of both the types were produced from the original CT/50 test specimens used in the 80ies for the fracture toughness tests of pressure vessel steel 15CH2NMFA.

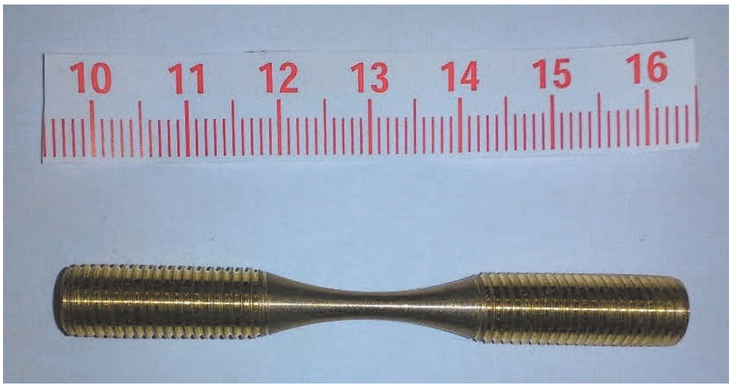


**Figure 1** Standard test specimen

### 3.2. Miniature test specimens

The origin of the miniature test specimens was the same as in the case of standard test bars. Thin sheet metal plates were cut off the CT/50 test specimen sides, then ground to a thickness of about 1 mm and brushed by 400 and 1000 grain grinding paper.

Testing itself began by removing the sample from the sheet and grinding the surface influenced by water jet. After the subsequent measurement, the specimen was clamped to testing equipment.

The miniature test specimens were produced in four variants (designated I - IV), see **Figure 2**.

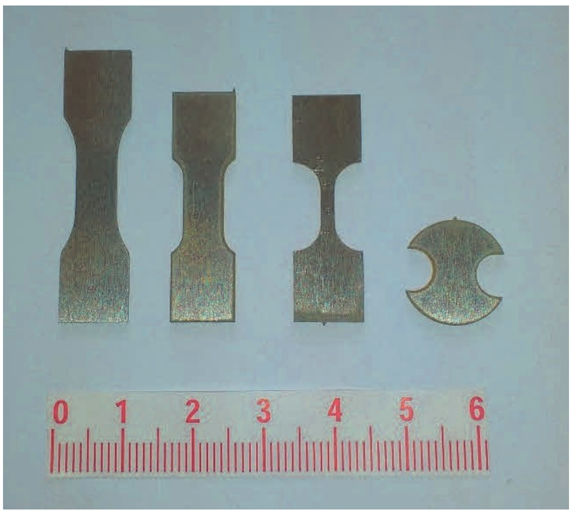


**Figure 2** Miniature test specimens

The difference between type I and type II consisted in different radius between the testing section and the clamping head of the specimen. The result of the smaller radius was the shorter total length of the specimen so that more specimens could be made of the sheet. In contrast to Type I specimens, where the fracture occurred in the head and was caused by the stress concentration from fixtures, the type II specimens fractured in the radius between head and the specimen body.

To eliminate these problems, type III was proposed, testing part of the specimen was reduced to increase the stress in the specimen body nevertheless in this case problems appeared during specimen clamping, esp. deformation of the specimens.

Type IV was developed by method Small punch test, where those types of specimens are designated for fatigue tests (SFT). By Finite element method (FEM) it was found that the stress concentration factor in the minimum cross section of this specimen is k = 1.33. This specimen is also the smallest-one from tested types, and thus more specimens can be cut off the same size of metal sheet [3,4]

The type IV specimen was decided to be the most suitable for fatigue tests of miniature samples and correlation of results with the results acquired on standard test specimens.

## 4. TEST EQUIPMENT

The tests of miniature and standard samples were performed on high frequency electromagnetic testing machine system Zwick Roell HFP 5100, see **Figure 3.** The advantage of electromagnetic resonant machines in comparison with servo-hydraulic systems consists in higher frequency (servo-hydraulic systems about 20Hz, electromagnetic resonant machines up to 180Hz).

**Figure 3** Zwick Roell HFP 5100

**Figure 4** Clamps for miniature test specimen

For the purpose of testing, clamps for miniature test specimens were developed, see **Figure 4**. The main requirements were toughness, possibility of clamping specimens with different head shapes and adjustability of the space between opposite inserts of the clamps for adjusting cohesiveness. Inserts of clamps were made in two variants, the first one with the pointed grooves and the second one with the rounded grooves. With respect to the stress concentration caused by the pointed grooves, the rounded grooves were preferred in testing, because the use of pointed grooves resulted in fractures in the specimen head area.

## 5. TEST PROCEDURE

There is no standard for testing of these types of miniature test specimens. Whole testing was performed fully experimentally. The fatigue testing was performed in the force controlled mode. All the tests were performed at cycle asymmetry R = 0.1, at the room temperature. The average frequency was approximately 87 Hz.

The beginning of the testing was rather informative. Different types of specimens, various attachment, machine setting and so on, were tested. Thanks to this knowledge, it was finally possible to determine fatigue characteristics of each melt, which were processed into tables and S - N diagrams (Wöhlers curves) [5].

## 6. TEST RESULTS

Obtained results are showed in **Figures 5-7**. Compare of results from all melts are in **Figure 8**.

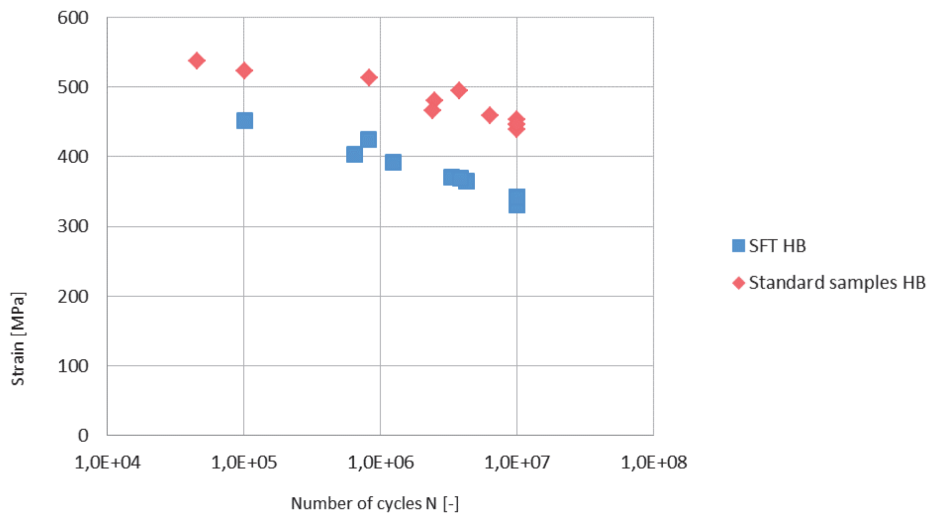


**Figure 5** Comparison of standard and miniature specimens of melt HB

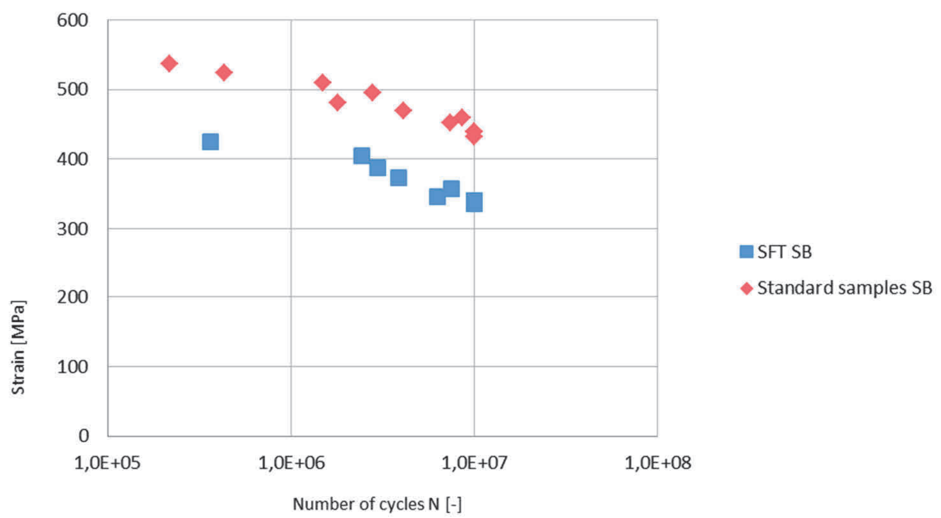


**Figure 6** Comparison of standard and miniature specimens of melt SB

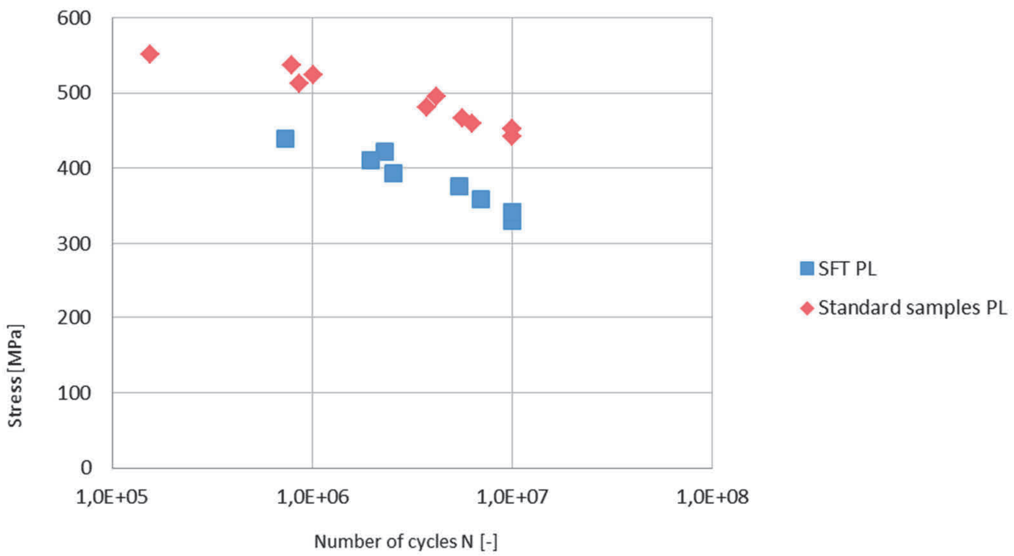


**Figure 7** Comparison of standard and miniature specimens of melt PL

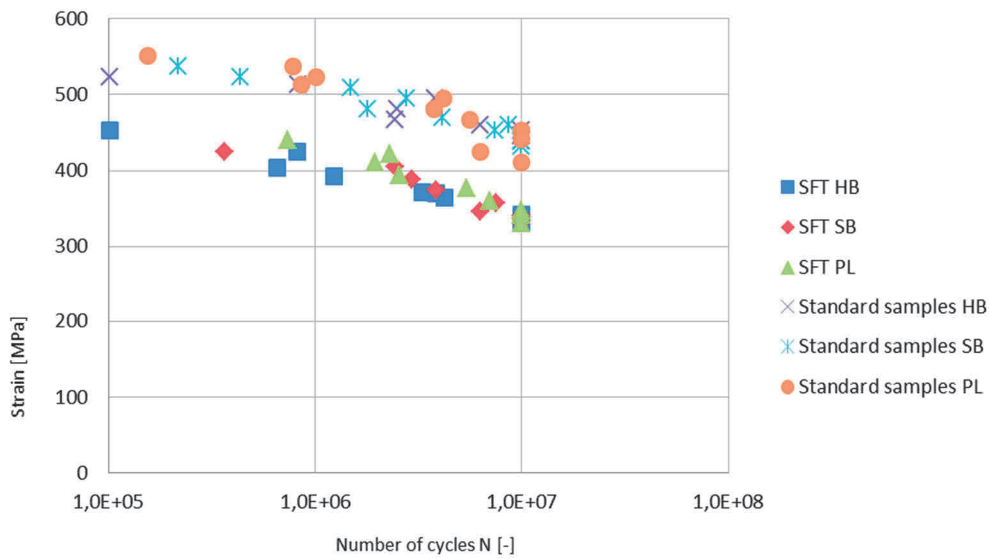


**Figure 8** Comparison of standard and miniature specimens, all melts

## 7. CONCLUSION

The fatigue limit of the test specimens was determined by the arithmetic mean of samples in which the number of cycles reached $10^7$. Fatigue limit of miniature test samples SFT was set to 338 MPa. Fatigue limit of traditional test samples made according to ČSN 42 0363 was set to 443 MPa. The correlation coefficient was determined from the relationship

$$\frac{\sigma_{mst}}{\sigma_{mSFT}} = k_{kor} \tag{1}$$

where $\sigma_{mst}$ is the maximum stress at the fatigue limit of the standard samples, $\sigma_{mSFT}$ is the maximum stress at the fatigue limit of the SFT miniature specimens and $k_{kor}$ is the correlation coefficient. After the calculation, $k_{kor}$ acquires value 1.31.

The results show a relative compliance of the results of the same sample types from three different melts. Therefore, this can be considered as a credible result of fatigue characteristics of the 15CH2NMFA steel.

Use of this small fatigue test samples is necessary f. e. at the applications, where not enough material for testing is available. Correlation of the SFT and traditional samples is important for getting information from the operated material, where the witness samples are not available. Therefore there is emphasis on creating of material correlation database.

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## REFERENCES

[1] RIBADAS, H., RUND, M. Evaluation of ductile fracture using micro-sample. In *CSI 2015: 1st International Conference on Structural Integrity.* Funchal: ASTM, 2015, pp 377- 384.

[2] ČSN 42 0363, *Metal testing. Fatigue testing of metals. Testing Methods.* Approved: 13.10.1986, MDT 669:620.194.8.

[3] VOLÁK, J. P92 and 15CH2NMFA Steels - A Comparsion of Fatigue Characteristics obtained on standard and miniature test specimens. In 7th International Conference on Fatigue Design, Fatigue Design 2017. Senlis: ICFD, 2018, pp 824-829.

[4] CHVOSTOVÁ, E. *Aplication of miniaturized test specimens for evaluating of mechanical properties and resistanceness against brittle cracks*. Pilsen: Dissertation. University of West Bohemia in Pilsen. Faculty of mechanical engineering, 2016. 92 p.

[5] PLUHAŘ, J. *Physical metallurgy and material boundaries: a nationwide university textbook for mechanical and metallurgical faculties of technical colleges*. Prague: SNTL Prague, 1987. 286 p.