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# INFLUENCE OF OPERATING CONDITIONS ON HIGH-CYCLE FATIGUE PROPERTIES OF HIGH ALLOYED STEEL X20

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## ABSTRACT
*In this paper, the effect of service temperature and life on high-cycle fatigue properties of base metal, steel X20 CrMoV 12-1, has been analysed. The effect of service conditions has been analysed by testing the new material and material that was in service for 116000 hours. The investigations have included determination of permanent fatigue strength at room and operating temperature. These investigations and their analysis should provide a practical contribution to assessment of behaviour of high alloy steel X20 under variable loading, thus ensuring safety in operation of the components in thermal power plants.*
**Key words**: High alloy steel X20, high cycle fatigue, fatigue strength.

## 1. INTRODUCTION
Some components of process equipment in thermal power plants, operating at elevated temperatures, are critical due to service conditions, particularly after long service period, exceeding the accepted nominal service life. Experienced failures of these components endangered not only human lives and safe operation of a plant, but affected the environment, too. In order to identify the quality and reliability of the material exposed to the effects of elevated temperatures in thermal power plants, mechanical properties of X20 steel were tested.
One of most frequently used steels for operation at elevated temperatures and under high pressure, at the same time corrosion-resistant, is steel designated as X20, mainly designed for steam lines and pipelines in thermal power plants because of its good strength and ductility at elevated temperatures. Tendency to minimise the wall thickness of the steam lines for required steam pressure can be accomplished only with steel of adequate properties.
Therefore, it becomes more and more important to prolong service life and to revitalise the components in thermal power plants, as well as to find the methods to keep the old power stations in operation for 40-50 years, and even longer [1]. Preliminary studies of Electric Power Research Institute (EPRI [2], Centro Elettrotecnico Sperimentale Italiano (CESI) [3] and European Creep Collaborative Committee (ECCC) [4] have shown that the costs of revitalisation of typical thermal power plants can amount to 20-30% of the costs for construction of a new thermal power plant. In such a case, revitalisation means only a guarantee of complete utilisation of life through selective

replacement of the components by other components of updated design. Main approach to revitalisation is an assessment of remaining service life.
For service safety of structures in processing equipment for operation in thermal power plants, very important properties are those describing the phenomenon of crack initiation under variable loading. Fatigue crack initiation at structurally smooth and homogeneous forms still cannot be described by some simple functions of loading, stress, material properties and cross-section; therefore, empirically derived functions are used, as a rule induced by thorough experimental and laboratory testing. Generally accepted property for that case is fatigue strength that determines the level of loading at which no crack occurs on smooth specimens.
The effect of service conditions (service life and temperature) on high-cycle fatigue properties in steel X20 was analysed by testing the new material and material that had been in service for 116000 hours. Testing of new and used steel included determination of permanent fatigue strength and design of Veler's curve.
The results obtained by testing and their analysis should provide a practical contribution to assessment of quality of X20 steel, aimed at revitalisation and extension of service life of vital components in thermal power plants made of high alloy steel for elevated temperatures.

## 2. MATERIAL

For assessment of the effect of service temperature and life on fatigue properties of steel *X20* designed for manufacture of vital components in thermal power plants, we had a sample of new pipe (*N*) and a sample of a pipe that had been in service for approx. 116000 hours (*U*). Both samples were the pipes ∅450 x 50 mm. Chemical compositions of tested pipes are given in Tab. 1 [5].

*Table 1: Chemical composition of tested pipe samples*

| **Charge No.** | **Chemical composition, mass %** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **C** | **Si** | **Mn** | **P** | **S** | **Cr** | **Mo** | **Ni** | **V** |
| **New pipe (N)** | 0,21 | 0,27 | 0,563 | 0,017 | 0,006 | 11,70 | 1,019 | 0,601 | 0,310 |
| **Used pipe (U)** | 0,22 | 0,31 | 0,539 | 0.019 | 0,005 | 11,36 | 1,033 | 0,551 | 0,314 |

## 3. TEST RESULTS

Testing of the effect of service conditions on behaviour of base metal, steel *X20*, under variable loading was performed on the sample of new material and material that had been in service for 116000 hours [6]. These tests were performed in order to determine the spots in *S-N* diagram (construction of Veler's curve) and permanent fatigue strength, $S_f$ [7]. The specimens were shaped and sized according to ASTM E466 [8]. Tests were performed on high-frequency pulsating device AMSLER.
High-frequency pulsator can induce sinusoidal alternating load ranging from -100 kN to + 100 kN. Mean loading and loading amplitude were registered with an accuracy of ±50 kN. Achieved frequency varied from 110 to 174 Hz, depending on loading value and tested temperature. In order to make an assessment of material behaviour under variable loading as complete as possible, and having in mind the dimensions of the specimens, the most critical case of variable loading was treated, i.e. alternating variable loading tension-pressure (R = -1). The results of testing under variable loading are graphically presented in a form of *S-N* (Veler's) curve in Fig. 1 from the sample of new pipe made of steel X20, and Fig. 2 from the sample of used pipe made of steel X20 [6].
In this test, as a rule, only the number of load variations until fracture occurs is determined at constant-range loading, and the standard requires only a datum on stress level at which fracture does not occur after certain number of cycles (usually between $10^6$ and $10^8$ cycles). For steel materials, ASTM E468 defines permanent fatigue strength, $S_f$, after $10^7$ cycles [7]. Therefore, this test is extremely expensive and justifiable only when the data are necessary for design, mainly from the point of view of fatigue and fracture mechanics, i.e. when the components exposed to long-term variable loading within total projected life of structure should be designed.

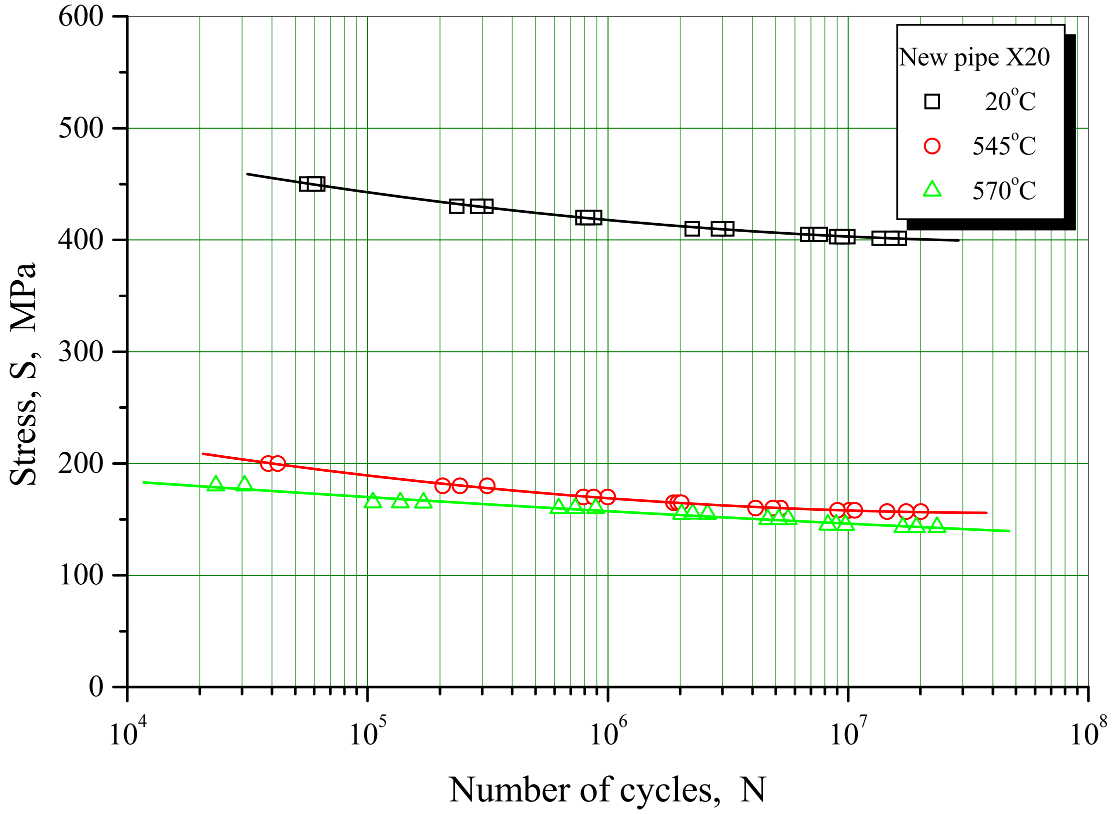


*Figure 1. S-N diagram of the specimens taken from the sample of new pipe made of steel X20 [6]*

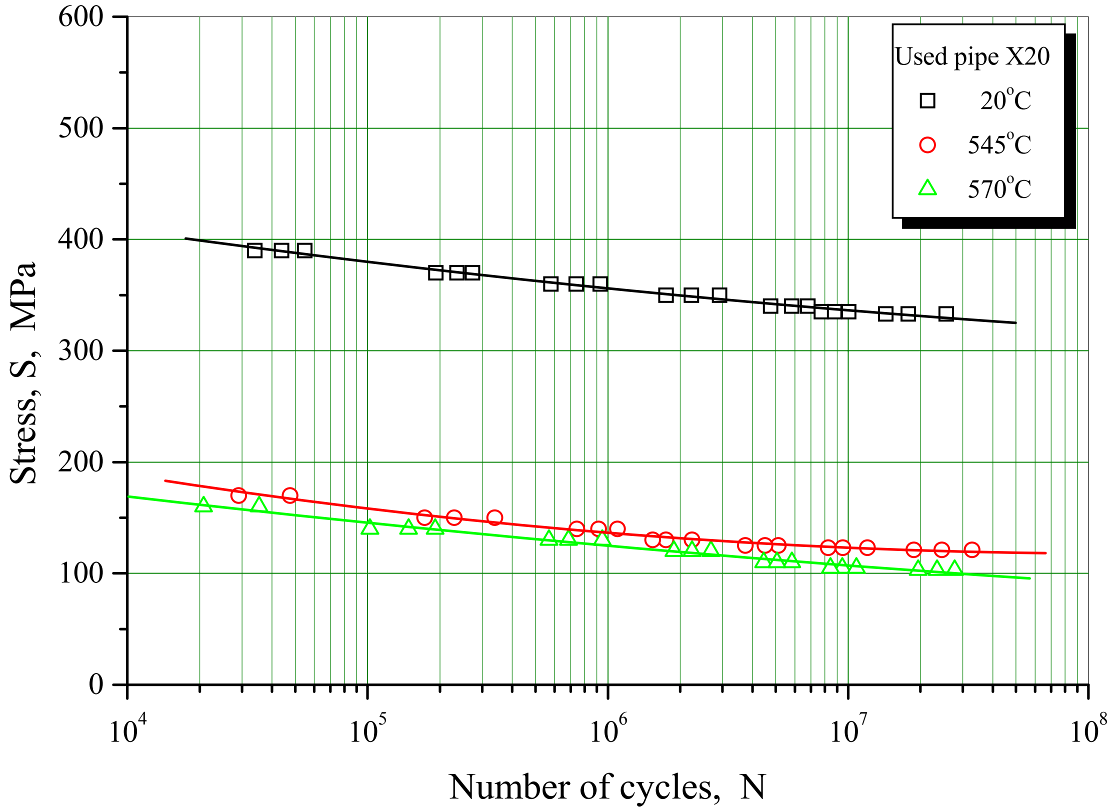


*Figure 2. S-N diagram of the specimens taken from the samples of used pipe made of steel X20 [6]*

## 4. THE ANALYSIS OF THE RESULTS

Analysing the results obtained by fatigue testing of smooth specimens in order to construct Veler's curve and to determine permanent fatigue strength, we can see that service life and testing temperature affect the values obtained for permanent fatigue strength. At room temperature, obtained value of fatigue strength is 79% of yield stress for new material, and 71% for used material. At operating temperature of 545°C, obtained value of yield stress is 65% for new material, and 55% for used material. At peak operating temperature, the value of permanent fatigue strength is 64% of yield stress for new material, and 53% for used material. If we consider the effect of the type of loading, we can see that the effect of service life is much stronger in fatigue testing than in static testing [6].

## 5. CONCLUSION

Based on the above mentioned, one can conclude that:

- Period of exploitation (new and used material) affect the values of permanent fatigue strength so that new material has higher resistance to crack initiation in smooth structural forms;
- Testing temperature also affects the values of permanent fatigue strength. The value of permanent fatigue strength decreases with increase of testing temperature. The samples tested at room temperature have the highest fatigue crack growth rate and the lowest resistance to crack propagation. Crack propagation resistance increases with increase of testing temperature.

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