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FATIGUE PERFORMANCE COMPARISON OF STRENX 700 AND 55NiCrMoV7 STEELS

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Abstract

The increasing demand for lightweight and reliable structural components and tools in manufacturing engineering creates a need for accurate data regarding the fatigue performance of high-strength and tool steels. This paper presents an experimental and comparative investigation of the fatigue behavior of STRENX 700, a high-strength structural steel, and 55NiCrMoV7, a thermally stable hot-work tool steel. Fatigue tests were conducted using a stress-controlled, fully reversed tension-compression loading regime (R = –1) on smooth “dog-bone” specimens. The resulting S–N curves were used to evaluate fatigue strength and determine the material parameters using Basquin’s relation. The results provide insight into the fatigue properties of these steels that have different industrial applications, but are tested under the same conditions. The fatigue performance, advantages, and trade-offs of each steel grade are discussed.

1. Introduction

Fatigue failure plays a crucial role in the durability of tools and components used in forging, turning (lathes), milling operations, and other related machining processes, where they are subjected to intense and repeated mechanical stresses. Tool steels like 55NiCrMoV7 [1] are often selected for these parts due to their toughness and thermal stability under elevated temperatures.

Steel 55NiCrMoV7 is most commonly used in forging dies and tooling under thermomechanical fatigue, because it has very good resistance to thermal shock and cracking, good mechanical properties at room and elevated temperatures, relatively high toughness at room and low temperatures, etc. Also, after heat treatment, this steel has good dimensional stability. It is intended for the manufacture of all types of forging dies and tools for hot work, molds for gravity casting of metals and plastics, tools for extrusion, etc. On the other hand, structural steels such as STRENX 700 [2] are known for their high yield strength and are optimized for lightweight structures, due to their high strength-to-weight ratios. In order to have an optimum machine design, considering the fact that 55NiCrMoV7 usually cost more, engineers need to choose the material of each part carefully, to use high-strength steel where possible, and to address thermomechanical fatigue where needed [3]. Engineers require comprehensive comparative fatigue data concerning these two types of steel in order to make the best decision, however, the current state of the art literature lacks direct comparison between them using the same testing equipment under the same conditions. This study aims to fill that gap.

2. Materials and Methodology

The STRENX 700 is a high-strength, low-alloy steel optimized for weldability and strength, with a nominal yield strength of around 767 MPa. 55NiCrMoV7 is a hot-work tool steel known for its excellent toughness, thermal shock resistance, and fatigue endurance after quenching and tempering [4].

Chemical compositions of steels STRENX 700 and 55NiCrMoV7 are given in Tables 1 and 2, respectively.

Table 1. STRENX 700 Chemical composition (wt. %):

C	Si	Mn	P	S	Al	Nb	V	Ti
0.11	0.093	0.64	0.009	0.017	0.017	0.088	0.19	0.14

Table 2. 55NiCrMoV7 Chemical composition (wt. %):

C	Si	Mn	P	S	Cr	Ni	Mo	V
0.55	0.3	0.7	0.035	0.035	1.1	1.7	0.5	0.12

55NiCrMoV7 was subjected to quenching and tempering to its optimal hardness range: 42–45 HRC.

To ensure uniformity and precision across all fatigue tests, cylindrical "dog-bone" specimens were meticulously machined from the STRENX 700 and 55NiCrMoV7 steel samples, adhering strictly to pre-defined internal standards that align with established guidelines [5]. The specimens were prepared to have a minimum diameter of 6.35 mm in the middle, where the failure occurs, and an external diameter of 12.7 mm for gripping by the machine. Dimensions of the specimens are shown in Fig. 1., while the actual untested specimen is shown in Fig. 2.

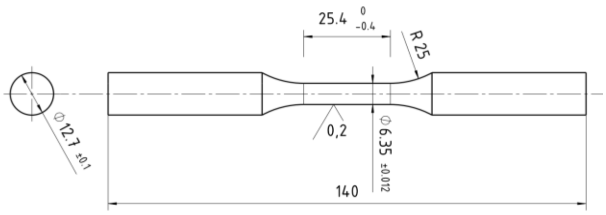

Fig. 1. Dimensions of the used dog-bone specimens

Fig. 2. Actual specimen before testing

2.1 Static testing for mechanical characteristics assessment

First, a Shimadzu Corporation servo-hydraulic testing machine (EHF EV101K3-070-0A) with a force of ±100 kN and ±100 mm stroke was used to perform uniaxial tensile tests on the specimens in order to ascertain their mechanical characteristics, i.e., static strength qualities [6]. Schematics of the testing equipment is shown in Fig. 3., while the actual testing machine and the used MFA25 extensometer [7] are shown in Fig. 4. and Fig. 5. respectively.

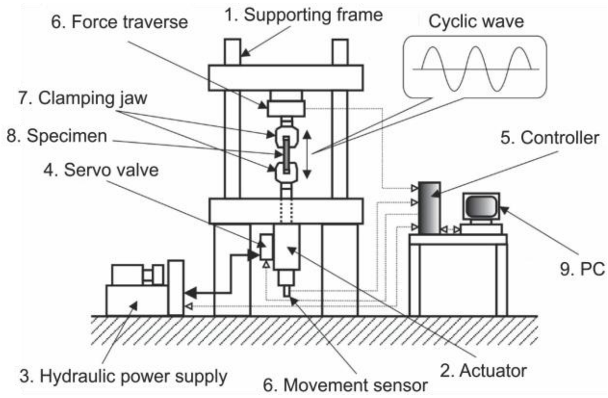

Fig. 3. Schematics of the testing equipment

Fig. 4. Shimadzu EHF EV101K3-070-0A

Fig. 5. MFA25 extensometer

Obtained mechanical characteristics of STRENX 700 and 55NiCrMoV7 grade steel are shown in Table 3.

Table 3. Mechanical characteristics of STRENX 700 and 55NiCrMoV7

Steel Grade	STRENX 700	55NiCrMoV7
Yield Strength $\sigma_{0,2}$ (MPa)	767.97	1450
Tensile Strength σ_M (MPa)	818.08	1600
Young's Modulus E (GPa)	228.89	212

2.2 *Fatigue testing*

Uniaxial fatigue testing was conducted at room temperature under a fully reversed stress ratio (R = –1) using smooth, cylindrical specimens. Stress-controlled loading was applied using a servo-hydraulic testing machine in accordance with ASTM E468 [8] and E739 [9] standards. For the STRENX 700 specimens [10], the fatigue testing was performed at load levels corresponding to ~70%, 65%, 60%, 45% and 40% of the material's yield strength (767.97 MPa), specifically 540 MPa, 500 MPa, 450 MPa, 350 MPa, and 300 MPa, respectively. Similarly, the 55NiCrMoV7 specimens were subjected to load levels that mirrored percentages of the STRENX 700's yield strength. Frequencies between 10–15 Hz were used depending on stress amplitude levels.

The fatigue life for each specimen was measured as the number of cycles to failure, defined by a complete fracture or separation of the specimen into two parts.

3. Results

The fatigue performance of STRENX 700 and 55NiCrMoV7 steels under cyclic loading is best visually presented using the S-N curves derived from the experimental data. These curves plot the applied stress level against the number of cycles to failure for each material, offering a clear comparison of their fatigue resistance.

Semi-log S-N curve for STRENX 700 obtained by interpolation and extrapolation of experimental results is shown in Fig. 6.

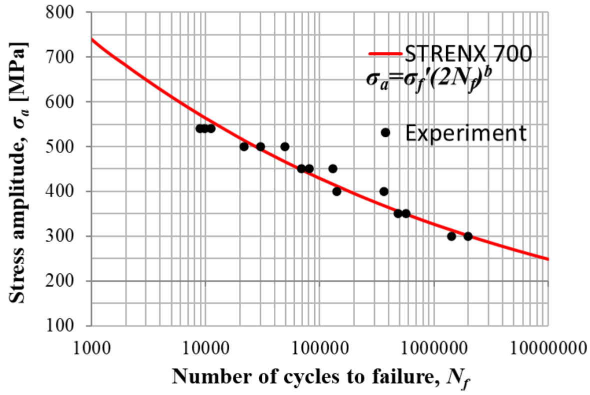

Fig. 6. S-N curve for STRENX 700

Likewise, the semi-log S-N curve for 55NiCrMoV7 steel obtained by interpolation and extrapolation of experimental results is shown in Fig. 7.

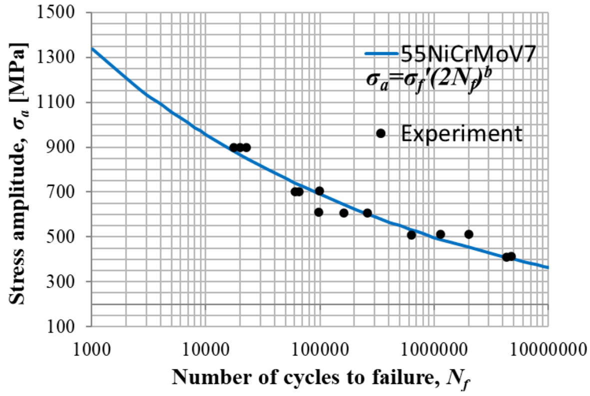

Fig. 7. S-N curve for 55NiCrMoV7

A diagram combining semi-log S-N curves for STRENX 700 and 55NiCrMoV7 is shown in Fig. 8.

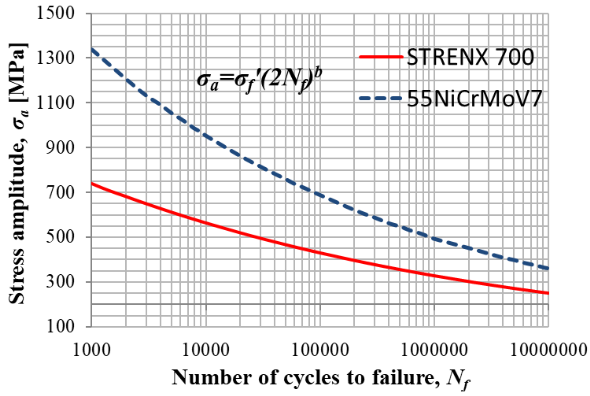

Fig. 8. S-N curves for STRENX 700 and 55NiCrMoV7

Steel 55NiCrMoV7 has a steeper S–N curve with better performance in the low-cycle fatigue regime but potentially reduced endurance in very high-cycle fatigue, compared to STRENX 700 which has a flatter S–N curve and whose fatigue performance does not decline as much when loaded with high-cycle fatigue.

55NiCrMoV7 shows superior performance at higher stress levels due to its toughness and tempered martensitic structure, making it suitable for heavy-duty and impact-loaded applications. This advantage diminishes as the number of cycles increases, as can be seen from Fig. 8.

The fatigue life results were processed to construct S–N curves and subsequently to determine parameters used in Basquin equation Eq. (1):

$$\frac{\Delta\sigma}{2} = \sigma_a = \sigma_f' \left(2N_f\right)^b, \quad (1)$$

where: σ_a is the true stress amplitude, and σ_f' is the fatigue strength coefficient. Furthermore, b is fatigue strength exponent, while $2N_f$ is the number of cycles to failure. For the analyzed steels, fatigue parameters are given in Table 4.

Table 4. Fatigue properties:

Steel Grade	Fatigue Strength Coefficient σ_f' [MPa]	Fatigue Strength Exponent b
STRENX 700	1814.61	-0.1181
55NiCrMoV7	3737.73	-0.1465

The Basquin parameters, calculated from the S-N curve data, are essential for quantitatively assessing the fatigue behavior of materials [5]. These parameters provide insights into the fatigue strength and fatigue life expectancy under varying stress conditions.

4. Conclusions

The findings of this study are consistent with previous research indicating that the fatigue life of materials is significantly influenced by their microstructure and mechanical properties [6].

This study demonstrated that while STRENX 700 offers comparable performance in high-cycle fatigue for structural applications, 55NiCrMoV7 holds advantages in low-cycle scenarios, as well as thermal resistance and cyclic toughness, particularly in high-load or thermally demanding environments. These findings may be used to guide material selection in designing metalworking machinery, as the price of 55NiCrMoV7 can be up to three times higher than that of STRENX 700, depending on grade/form and sourcing, although the difference is usually not that great.

Acknowledgments

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