# An Assessment for Fatigue Strength of Shaft Parts Manufactured from Two Phase Steel

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**Abstract.** Duplex stainless steel (Duplex) is a new material that has superior properties compared to other stainless steels in terms of avoiding corrosion stress and extremely good yield strength, high flow resistance and cheaper than austenite stainless steel series. However, fatigue strength that always leads to destruction occurs during the working process of axle-shaped machine parts under phase changes. In this paper, the evaluation of fatigue strength of Duplex steel to predict the longevity, maintenance plan for axial-shaped machine parts as well as the advanced mechanical heat treatment mode for Duplex steel are investigated. Samples are made from Duplex SAF 2205 (ISO 1143: 2009) to run fatigue tests by "Staircase" method to determine fatigue strength for Duplex 2205. In addition, this study also provides heat treatment mode for Duplex 2205: heating temperature 950 °C, heat retention time of 15 min and cooling down in the same furnace. The results indicate that supplied-stage Duplex 2205 steel will not be destroyed by fatigue under load under phase changes with 360 MPa stress, which is about 50% higher than AISI 304 (240 MPa) stainless steel. Duplex 2205 steel after heat treatment is enhanced mechanical properties and better durability than Duplex 2205 steel in the supply state.

**Keywords:** Fatigue strength · Duplex stainless steel · DSS 2205 · Duplex heat treatment

## 1 Introduction

Duplex stainless steel is also known as two-phase steel because it has a structure consisting of ferrite phases and austenite phases with approximately equal proportions and intermingling. With such a two-phase construction they will have the best performance combination of the two phases. In the chemical composition of steel contains a high content of chromium (21–23%), it has twice the strength of austenite stainless steel and has a significantly better ductility than ferrite stainless steel. This steel can be mentioned as LDX 2101, SAF 2304, 2205, 253MA [1].


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The axle-shaped machine parts are commonly used in the mechanical industry, it is often subjected to corrosion due to friction and stressed under load. During the working process, there is little downtime so machine parts may be damaged, especially shaft parts…. causing the situation of stopping production to carry out maintenance, repair, and replacement of machine parts. The replacement of shaft parts is inevitable, the shaft replacement process can be time consuming, costly, and reduces the machine's performance resulting in low productivity. Therefore, we need to research more new materials such as two-phase steel (Duplex), with higher durability and longevity to put into the manufacture of machine parts, to meet the requirements of high-strength operation of machines, increasing stability and longevity of machines are essential in the development of science and technology. Duplex stainless steel solves the above problems, it has good corrosion resistance, high durability, and cheaper price than other common stainless steels. Stainless steel manufacturing technology often involves forming methods such as rolling, forging, casting, and machining. Materials such as Duplex stainless steel will have a different internal microstructure after forming processes due to the different properties of the two phases. Duplex steel is used in the paper industry, automobile, aviation, and ship industries… [2] to improve the durability of shaft-shaped machine parts that operate at high frequency and intensity, easily damaged and destroy. Cast Duplex Steel was first produced in Finland in 1930 and patented in France in 1936 [3]. Duplex stainless steel is gradually being used in Europe to replace traditional steels according to Japanese JIS standards such as: SUS 201, SUS 304, SUS 316… European countries are always at the forefront of research. and development of this steel. There have been studies on fatigue strength when changing the ferrite phase ratio of Duplex steel [4], the results showed that when changing the composition of the ferrite phase, the fatigue strength of steel is affected.

To aid in predicting the fatigue life of a component, fatigue tests are carried out using coupons to measure the rate of crack growth by applying constant amplitude cyclic loading and averaging the measured growth of a crack over thousands of cycles. However, there are also a number of special cases that need to be considered where the rate of crack growth obtained from these tests needs adjustment. Such as: the reduced rate of growth that occurs for small loads near the threshold or after the application of an overload; and the increased rate of crack growth associated with short cracks or after the application of an underload [5]. This paper focuses on the fatigue strength of Duplex 2205 steel. In addition, the heat treatment mode to improve the mechanical properties for this steel is also studied.

## 2 Theoretical Basis

### 2.1 Fatigue

Fatigue is the weakening of a material caused by cyclic loading that results in progressive and localized structural damage and the growth of cracks. Once a fatigue crack has initiated, it will grow a small amount with each loading cycle, typically producing striations on some parts of the fracture surface. The crack will continue to grow until it reaches a critical size, which occurs when the stress intensity factor of the crack exceeds the fracture toughness of the material, producing rapid propagation and typically complete fracture of the structure.

The fatigue limit of a material ($S_r$) under a given condition is the maximum value of the time-varying stress corresponding to a number of fundamental stress cycles without the material being destroyed. Each material has its own number of fundamental stress cycles ($N_0$) [6].

The fatigue curve is based on the results of fatigue tests, the fatigue curve is designed to show the relationship between the varying stresses ($\sigma$) with the corresponding number of stress cycles (N) (Fig. 1). If the stress is reduced to a certain limit $\sigma_r$ for some materials, the life of N can be greatly increased without the part of the machine being destroyed. The value $\sigma_r$ is called the fatigue strength (long term) limit of the material.

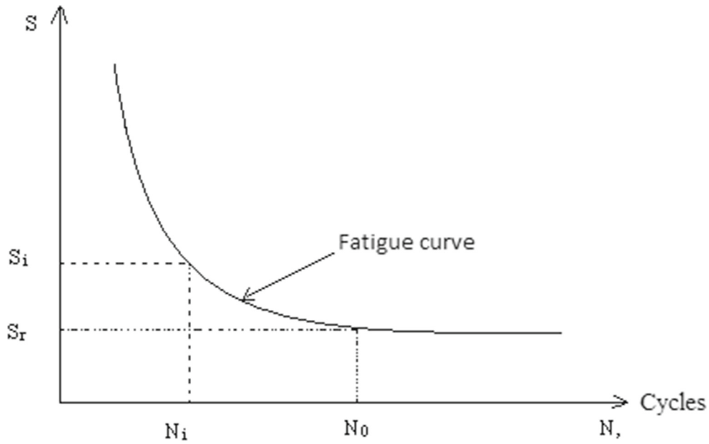


**Fig. 1.** Wöhler fatigue curve

## 2.2 Theoretical Basis of Heat Treatment

In theory, the metal is heated at a specified temperature, then the temperature is maintained for a certain period. After that, the metal is cooled down at a predetermined speed to achieve the required texture and properties of the metallic material. (Fig. 2) [7].

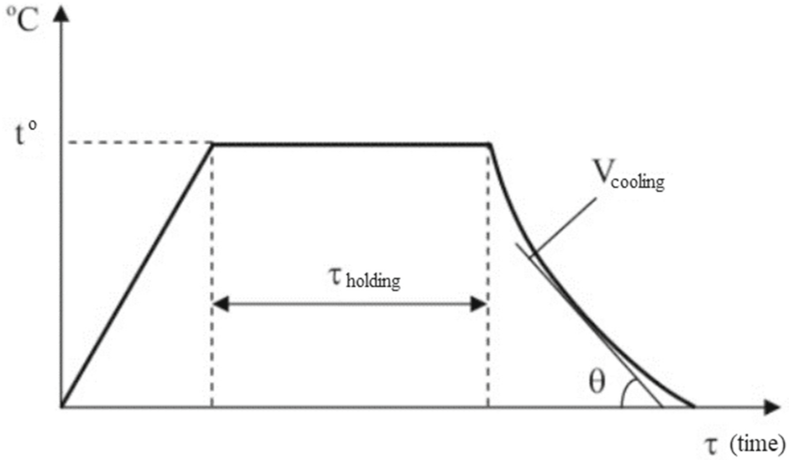


**Fig. 2.** Characteristic parameters of the heat treatment process

# 3 Experiment and Results

## 3.1 Experimental Equipment

Fatigue strength tests were performed on the machine of the research group of mechanical engineering and environment (REME Lab) of the Ho Chi Minh City University of Technology Education. Fatigue testing machine as shown in Fig. 3 (Table 1).

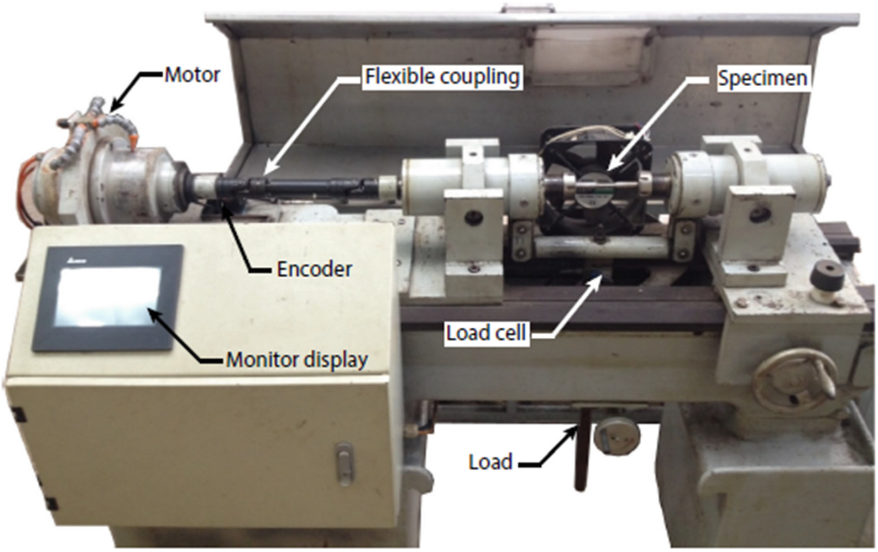


**Fig. 3.** Fatigue testing machine

**Table 1.** Specifications of fatigue resistance testing machine

| Specifications | Value |
|---|---|
| Engine power (kW) | 2 |
| Spindle speed (rpm) | 500–10000 |
| Force exerted through the loadcell (N) | 20–2000 |
| Sample size (mm) | 12–15 |

### 3.2 Recommended Sample Parts

The standard specifies the part of a rotating bend fatigue test sample of nominal diameter 5–12,5 (mm) and specifies that the machining process does not residual stress concentration on the test sample. The purpose of fabricating a rotating bend fatigue test sample is to determine the fatigue properties of the material represented on an S-N (stress-cycle) curve. Based on ISO 1143: 1975 and actual fatigue testing machine conditions, sample parts of fatigue strength test proposed as shown in Fig. 5 (Fig. 4).

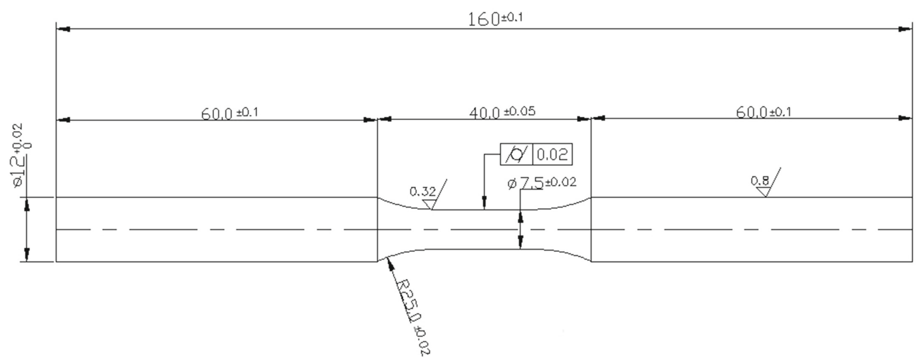


**Fig. 4.** Rotating bend fatigue test sample

### 3.3 Fabrication of Sample Parts

The test sample is machined from two-phase stainless steel (Duplex), grade 2205. Chemical composition after being analyzed by Spectro Max spectrometer (Germany) at Nam Long Construction Engineering Co., Ltd is shown in Table 2.

The parts are machined simultaneously on the Miyano LK-01 CNC lathe (Fig. 6) with the following cutting modes [7]:

- Cutting depth: t = 0,5 mm
- Feed rate: s = 0,2 mm/r
- Cutting speed: Roughing turning v = 1200 rpm, Finishing turning v = 2000 rpm

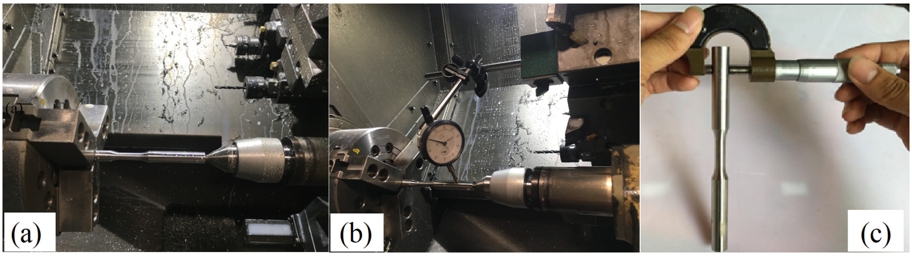


**Fig. 5.** (a) Machined parts on CNC lathes; (b) Check by clock comparison; (c) Check by panme

**Table 2.** Specifications of fatigue resistance testing machine

| Steel grade | Chemical composition (% mass) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cr | Ni | Mo | Mn | Si | P | S | C | Fe |
| 2205 | 21.48 | 5.54 | 3.57 | 1.63 | 0.529 | 0.0021 | 0.0053 | 0.045 | 66.5 |

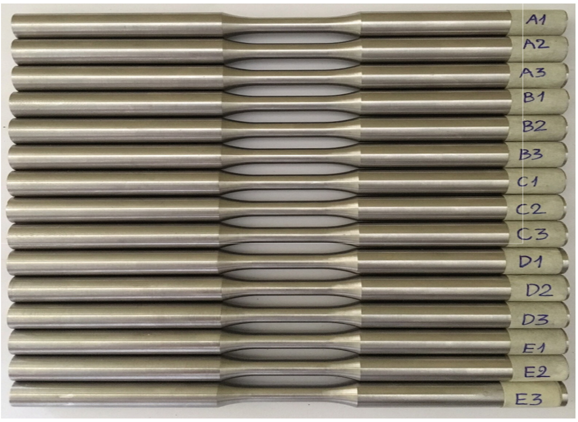


**Fig. 6.** Test sample in supply status of steel

### 3.4 Heat Treatment

– Metallographic specimen preparation

The parts used for metallographic specimen is a cylinder with the size 12 × 20 (mm), this size is suitable for the actual furnace conditions for easy implementation during the inspection. The microscopic organization test sample in the supply state is checked at two location: RD (Rolling Direction) and TD (Transverse Direction) positions. The purpose of this double-sided inspection is to know what the grain structure of the steel in the supply state looks like, thereby determining the appropriate heat treatment regime to uniformize the grain structure to serve the process of running the steel fatigue test in the heat treatment state (Fig. 7).

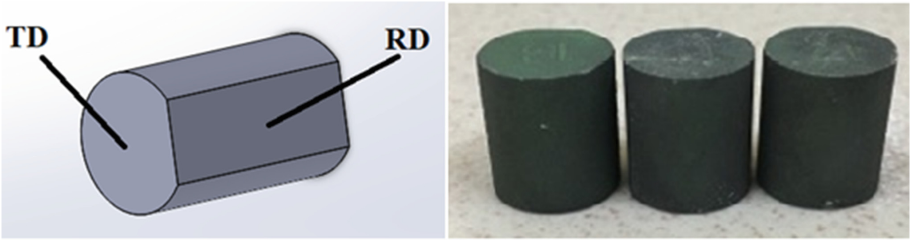


**Fig. 7.** (a) 3D sample design; (b) Metallographic specimen sample

– Etchant for Duplex steel 2205

Duplex 2205 steel has a high corrosion resistance so the use of etchanting solutions must be appropriate. The composition of the etchanting solution used includes distilled water 100 ml, ethanol 100 ml, HCl 100 ml, $CuCl_2$ 5 g, the etchanting time is 5 min [8].

– Metallographic specimen result of Duplex steel 2205 in supply state

Duplex 2205 steel in the supply state after etchanting (surface corrosion) was examined for microscopic organization on an optical microscope IMS-300. The results were observed in two cross sections (Transverse Direction - TD) and vertical section (Rolling Direction - RD) as shown in Fig. 8.

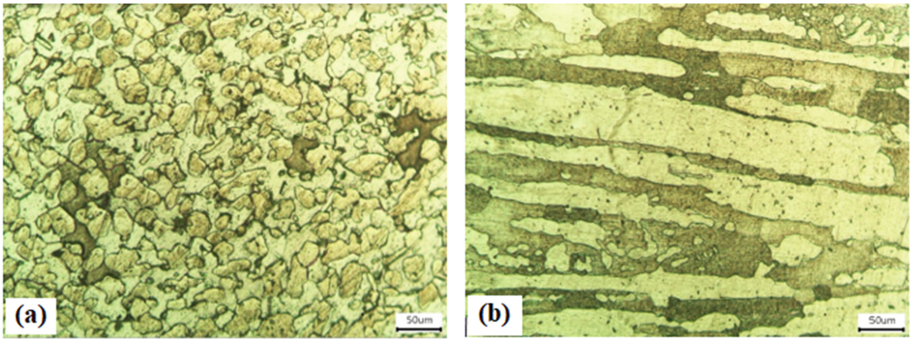


**Fig. 8.** (a) Transverse Direction – TD; (b) Rolling Direction - RD

In the supply state in the cross-section, the particles are round and evenly distributed, in the vertical section, the grain structure is elongated, this affects the machining process as well as the steel's cyclic load capacity. Therefore, processing the stretched grain structure by heat treatment, making the steel grain becomes more spherical so that the steel can be easily machined, improving the mechanical properties and durability of steel.

– Metallographic specimen result of Duplex steel 2205 in heat treatment state

The sample is subjected to heat treatment in many states, but in this study, the author proposes 3 states of heat treatment as follows:

**State 1:** The sample is heated at 500 °C for 6 h, cooled with air and the microscopic structure of Duplex 2205 steel after heat treatment has the shape and structure as shown in Fig. 9.

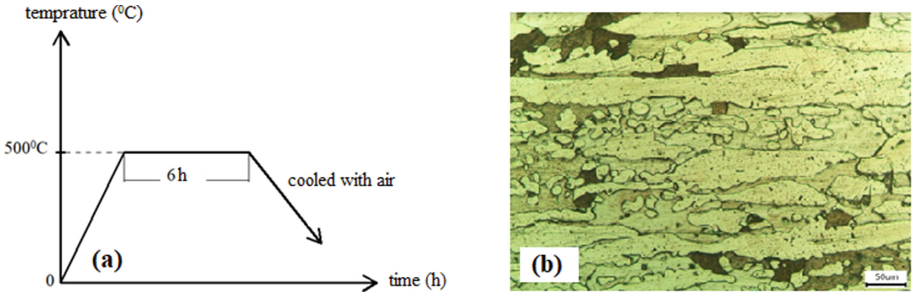


**Fig. 9.** (a) Heat treatment diagram; (b) Microstructure in state 1

In state 1, there was a transformation of the steel grain to the shape, but some particles still did not achieve the desired shape.

**State 2:** the sample is heated at 500 °C for 6 h, cooled with the furnace, the microstructure of Duplex steel 2205 after heat treatment in state 2 has the shape and structure as shown in Fig. 10.

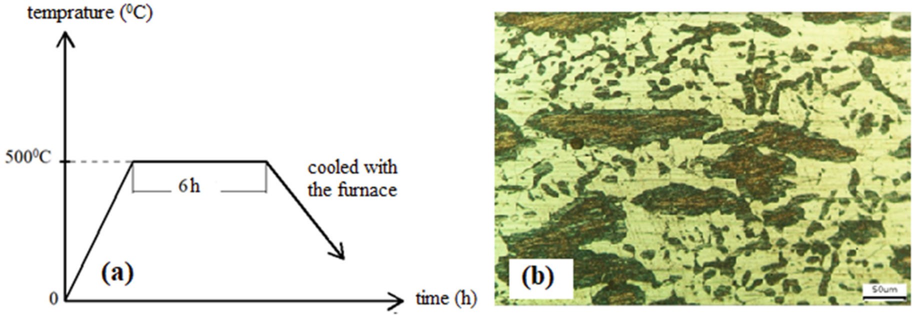


**Fig. 10.** (a) Heat treatment diagram; (b) Microstructure in state 2

In state 2, the majority number of steel grains had a pronounced change in shape and were more evenly arranged than in state 1. But in this state, the degree of steel recrystallization has not been completely. some large seeds.

**State 3:** the sample is heated at 950 °C for 15 min, cooled with the furnace, the microstructure of Duplex steel 2205 after heat treatment in state 3 has the shape and structure as shown in Fig. 11.

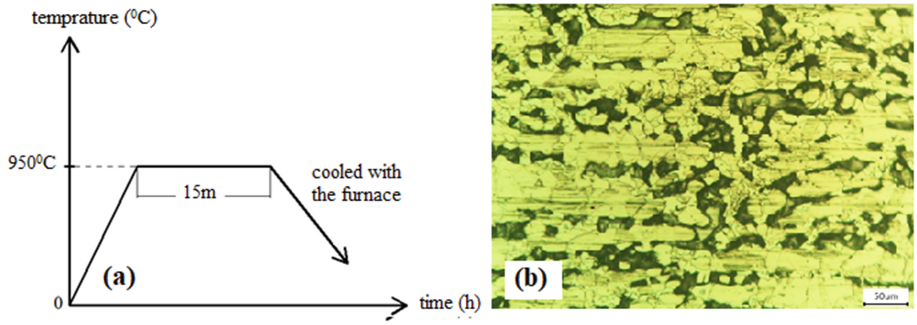


**Fig. 11.** (a) Heat treatment diagram; (b) Microstructure in state 3

In state 3, all steel grains have been small, with nearly the same shape and size, evenly distributed in the organization of steel.

After performing heat treatment in many states, we see that in state 3, the steel will achieve a stable state after restructuring the grain, small steel grains, more evenly distributed to improve the mechanical properties and durable for steel. From that result, we choose heat treatment mode in state 3 to heat treatment for the parts that needs to fatigue test.

### 3.5 Fatigue Test Process

A machine, which is called the four-point bending fatigue testing machine, was designed to examine the fatigue strength of the specimens (Fig. 3). There are four clamps in the machine to keep rotating bending specimen fixed. While the two external clamps force the specimen's movement vertically, the expected specimen's bending was created by the vertical sinusoidal of the two inside clamps. Fatigue was tested by a measured force mode, which was calculated by a load cell. The number of cycles to failure was recorded by an encoder near the motor spindle. Fatigue tests were carried out under rotating bending conditions with a stress ratio R of $-1$ and a loading frequency of 50 Hz. The fatigue strength is determined when specimen fracture occured or the number of cycles reaches $10^7$. Fracture of specimens is defined as the increase in vibration amplitude above a preset level.

Fatigue test process of Duplex steel 2205 are carried out in two states: supply state and heat treatment state. The parts are destroyed (Fig. 12), this is the weakening of a material caused by cyclic loading that results in progressive and localized structural damage and the growth of cracks.

From the above results, we plot the fatigue curve according to the collected data. The fatigue curve is a representation of the relationship between stress and cycle shown in Fig. 13.

The fatigue curve of the sample (Fig. 13) shows the cyclic load capacity of Duplex 2205 steel in the supply state and heat treatment state. In the supply state, when at the stress of 360 MPa the parts is not destroyed, reaching the value $10^7$. Thereby, we find that the Duplex 2205 steel in the supply state has about 50% higher strength than the other common stainless steels (AISI steels $10^7$ at a stress level of 240 MPa). In the state


**Fig. 12.** Parts are destroyed

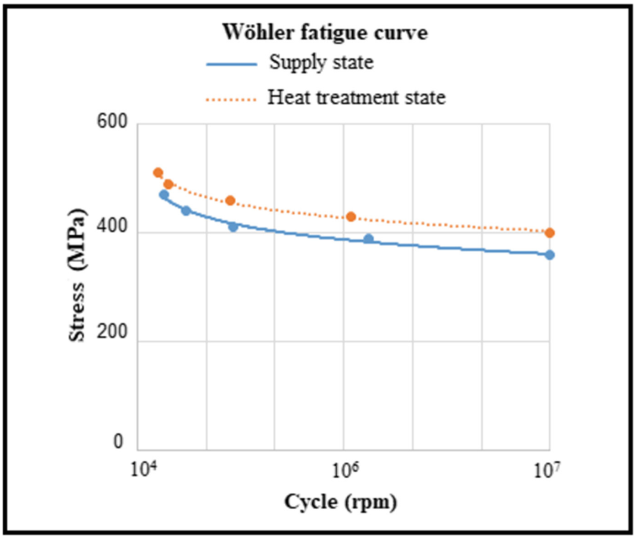


**Fig. 13.** Wöhler fatigue curve

of heat treatment, the parts reach $10^7$ with a stress level of 400 Mpa, so it has a higher strength than Duplex 2205 steel in the supply state about 11%.

## 4 Conclusions

The results achieved in this study:

Proposing sample parts for fatigue testing in accordance with ISO 1143: 1975 and proposed parts of tensile test specimens made in accordance with ISO 6892-1: 2009.

The study has performed a mechanical review of Duplex steel 2205 in the heat treatment mode as follows: temperature 950 °C, time 15 min and cooling with the furnace.

Determining the fatigue strength of shaft parts made from Duplex steel 2205 in the supply state with a value of 360 MPa, the parts reach $10^7$ cycles, about 50% higher than the common stainless steels.

Determining the fatigue strength of the shaft parts made from Duplex steel 2205 in the state of heat treatment, with a value of 400 MPa, the parts reach the cycle of $10^7$. The results show that, through heat treatment will make increased mechanical strength and fatigue strength by about 11% for Duplex 2205 steel, which is also worth considering in the part design process.

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