# TENSILE PROPERTIES OF Ti-3Al-8V-6Cr-4Mo-4Zr ALLOY AT DYNAMIC AND QUASI-STATIC CONDITIONS

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**Abstract**

Ti-3Al-8V-6Cr-4Mo-4Zr has a wide range of mechanical properties. The alloy is commonly used for springs and fasteners in aircraft and automobile industry, tubing in oil and gas wells, and for wires in sporting goods. This work is aimed at the analysis of Ti-3Al-8V-6Cr-4Mo-4Zr alloy behaviour during the tensile tests realized at dynamic as well as quasi-static conditions. In this research a non contact and material independent measuring system ARAMIS was applied. The influence of tensile test strain rate on selected mechanical properties was investigated. The nature of tensile fracture surfaces of the investigated alloy was also discussed. The investigations showed a significant influence of processing strain rate on the mechanical behaviour of the investigated alloy. The results of this research work can be helpful in the design of Ti-3Al-8V-6Cr-4Mo-4Zr alloy structural parts operating under high strain rate conditions.

**Keywords:** Titanium alloy, quasi-static conditions, dynamic conditions, mechanical behavior, tensile tests

## 1. INTRODUCTION

Ti-3Al-8V-6Cr-4Mo-4Zr alloy (Grade 19) belongs to the group of β-titanium alloys. Among the important properties of this alloy light weight (4.82 g/cm$^3$), good ductility and very high strength can be mentioned [1, 2]. This alloy has unique high - cycle fatigue properties due to the refined nature of their microstructure [3]. In addition to offering superior strength properties over Ti-6Al-4V, this alloy also provides higher creep resistance in the intermediate temperature ranges. Because of these advantages, this alloy has become a standard material for a particular niche of specialized applications which have included aircraft springs and underground tubes and casing equipment for gas and oil well operations. Due to excellent corrosion resistance to acids as well as seawater, applications of this titanium alloy to marine structures are also promising. It has also been used in fasteners and high-performance auto racing structural parts [3, 4.]. That is why the knowledge of the mechanical behavior of this alloy under dynamic conditions is required. This knowledge is reported for many materials which are subjected to rapid loads [5 - 7], and it also applies to chosen titanium alloys [8]. However, in the case of Ti-3Al-8V-6Cr-4Mo-4Zr alloy the number of information is quite limited, therefore the results of the realized studies can be helpful in the design of structural parts from this alloy.

## 2. MATERIAL UNDER INVESTIGATION AND EXPERIMENTAL PROCEDURE

As an initial material for his study, a Ti-3Al-8V-6Cr-4Mo-4Zr alloy bar with a diameter of 50 mm was used. Chemical composition of this alloy is shown in **Table 1**.

**Table 1** Chemical composition of Ti-3Al-8V-6Cr-4Mo-4Zr alloy in wt.% (specification: ASTM B265)

| C | Mo | Al | Zr | Fe | Cr | V | H | N | O | Y | Ti |
|---|---|---|---|---|---|---|---|---|---|---|---|
| <0.05 | 3.5÷4.5 | 3.0÷4.0 | 3.5÷4.5 | <0.3 | 5.5÷6.5 | 7.5÷8.5 | 0.03 | 0.03 | 0.12 | <0.005 | Bal. |

Plate tensile specimens were prepared from the investigated Grade 19 alloy by electro-discharge machining method. Then the surfaces were ground using abrasive paper, finally the specimens were polished to remove surface scratches. To measure the strains by means of grey scale correlation software, a grey scale pattern on the surface of the specimens was applied. The scheme of the tensile specimen is shown in **Fig. 1**, where also the dimensions in mm and the gauge length with applied grey scale pattern are displayed.

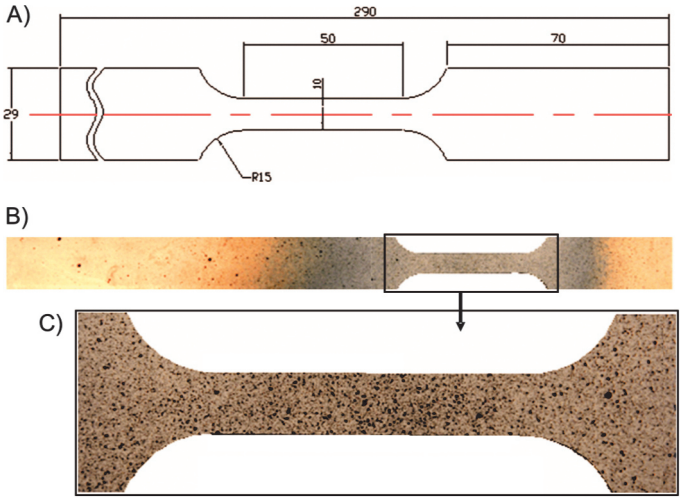


**Fig. 1** Tensile specimen used for static and dynamic tensile tests: A) - scheme of specimen, B) - specimen with grey-scale pattern, C) - gauge length

For the investigations and the characteristic of materials at high loading speeds INSTRON VHS 160/20 servo-hydraulic high velocity test system (SHP), available at the Institute of Lightweight Engineering and Polymer Technology (ILK) TU-Dresden, has been used. The SHP enables testing the materials and components at maximum force of 160 kN and high deformation speeds up to 20 $m \cdot s^{-1}$ [5]. The test equipment allows highly-dynamic tensile, shear and compression tests. The testing machine has a specially designed upper gripping device for gripping the tensile specimen at a defined testing speed. This design makes possible initial acceleration of the grip without loading of the specimen. After obtaining the test velocity, spacers are pushed out and the upper clamp grabs the specimen [6]. For means of strain determination a high speed camera Phantom v. 7.2 in combination with the grey-scale-correlation software ARAMIS was applied. This high speed camera is capable of taking up to 190.000 pictures per second. For the performed tensile tests, frame rates varied from 10 Hz at the testing speed 0.0001 $m \cdot s^{-1}$ and 50.000 Hz at 1.0 $m \cdot s^{-1}$. Tensile testing stand consisting of SHP system and Phantom v. 7.2 high speed camera is shown in **Fig. 2**.

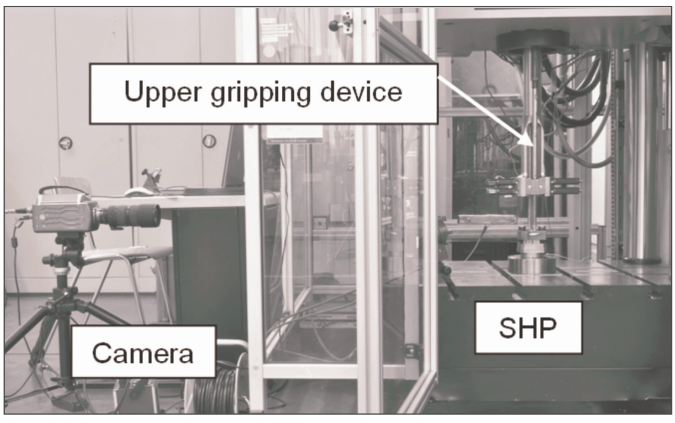


**Fig. 2** Tensile testing device Instron VHS 160/20 with high speed camera Phantom v. 7.2

Quasi-static and dynamic tensile tests were conducted at room temperature at testing speeds of 0.0001 $m \cdot s^{-1}$, 0.1 $m \cdot s^{-1}$ and 1 $m \cdot s^{-1}$. The reaction force is recorded with a Kistler 9017A, 400 kN piezoelectric load washer, mechanically preset at 200 kN [7].

## 3. RESULTS OF THE INVESTIGATIONS

### 3.1 Fracture of the sample during dynamic tensile test

**Fig. 3** shows recorded by high speed camera progress of fracture in the sample tested in tension at tensile test speed of 1 $m \cdot s^{-1}$. The changes of the temperature of tested samples were also recorded by the camera. The highest values of temperature are shown in white colour.

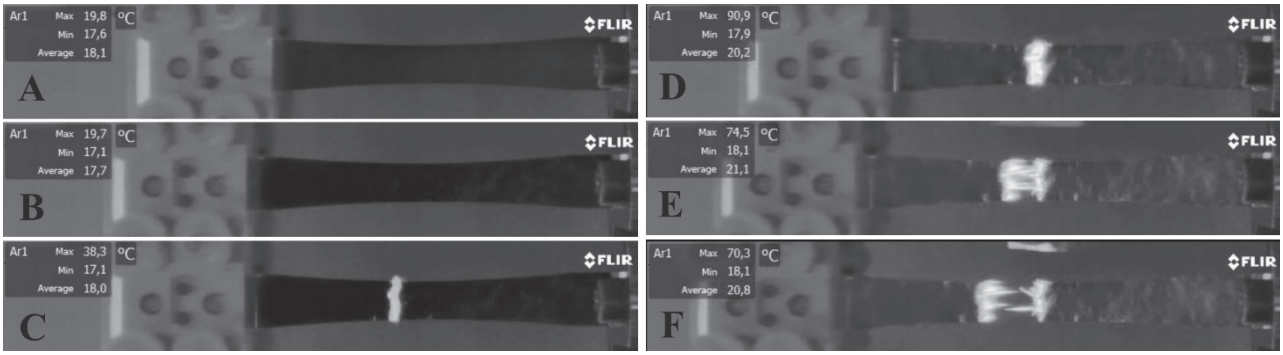


**Fig. 3** Chosen stages of fracture of Ti-3Al-8V-6Cr-4Mo-4Zr alloy sample recorded by high speed camera during dynamic tensile test at testing speed 1 $m \cdot s^{-1}$, and temperature changes in the area of fraction. A - F: successive stages of the test

During the fracture of the sample tested in tension at highest test speed (stages C - F presented in **Fig. 3**) an intense increase of the temperature in the area of the fracture was noticed. The highest temperature of 90.9 °C was observed in stage 3D showing the fracture and the start of the separation of two parts of the sample. At this stage of the test the work of deformation converted into heat causing a local increase of the temperature in the area of fracture of the sample. Next stages (**Fig. 3**, stage E and stage F) of tensile test performed at test speed of 1 $m \cdot s^{-1}$, the separation of two parts of the sample and drop in their temperature were observed. The separation of small parts of the sample in the area of fracture surface was also noticed (**Fig. 4**A). This could not be observed in the case of the samples tested at lower tensile test speeds.

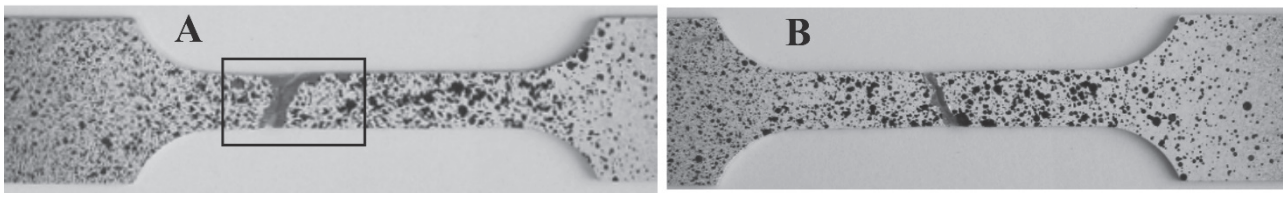


**Fig. 4** Gauge length of tensile specimens after tensile test at testing speed: A) 1 $m \cdot s^{-1}$, B) 0.1 $m \cdot s^{-1}$

### 3.2 Mechanical properties

Chosen examples of stress-strain curves obtained from the tensile tests are presented on **Fig. 5. Table 2** shows the average values of the fracture strength (FS), elastic modulus (E) and total strain to fracture (TSF) for each tested specimen.

**Table 2** Mechanical properties of Ti-3Al-8V-6Cr-4Mo-4Zr alloy determined in tensile tests

| testing velocity ($m \cdot s^{-1}$) | FS (MPa) | E (GPa) | TSF (%) |
|---|---|---|---|
| 0.0001 | 1201 | 100 | 7.5 |
| 0.1 | 1295 | 101 | 8.6 |
| 1 | 1370 | 93 | 6.0 |

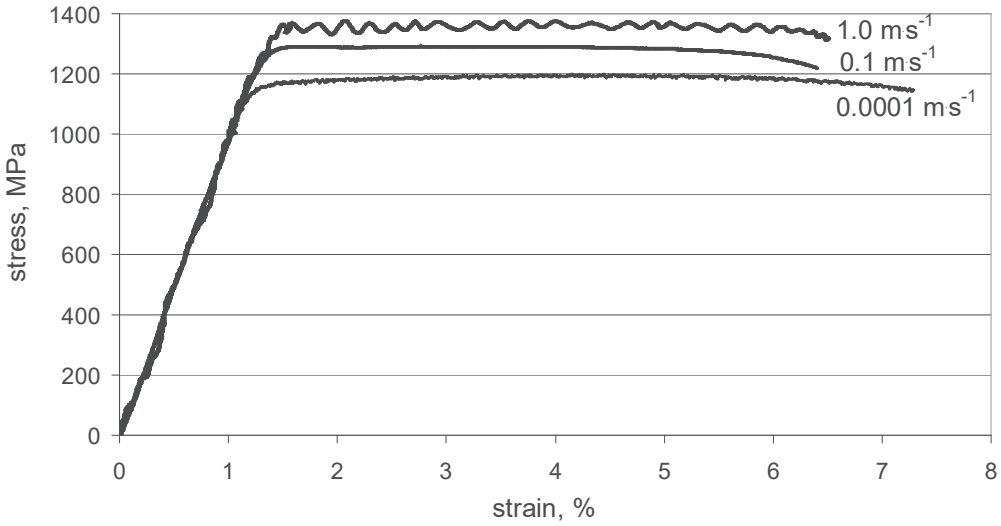


**Fig. 5** Influence of strain rate on the stress-strain curves obtained from the tensile tests performed on Ti-3Al-8V-6Cr-4Mo-4Zr alloy samples

The tensile tests performed on Ti-3Al-8V-6Cr-4Mo-4Zr alloy under dynamic conditions showed higher values of the fracture strength of the test samples in comparison to the fracture strength of the samples tested under quasi - static conditions (**Fig. 5**, **Table 2**). An increase of the tensile test strain rate resulted in the fracture of the samples at lower value of the total strain (**Table 2**). The changes of the tensile tests strain rate from 0.0001 (quasi - static conditions) to 0.1 $m \cdot s^{-1}$ did not influence the elastic modulus of the investigated material, while increase of this value to 1.0 $m \cdot s^{-1}$ caused a slight decrease of the elastic modulus.

### 3.3 Metallographic investigations

The fracture surfaces of the samples after tensile tests were examined on Hitachi S3500N scanning electron microscope. **Fig. 6** exhibits tensile fracture surfaces of Ti-3Al-8V-6Cr-4Mo- 4Zr alloy.

Most of the observed fracture surfaces exhibit dimples which are indicative of ductile rupture. Such nature of the fracture was observed in the case of all tested samples, regardless of tensile test speed. This is most likely connected with phase composition of the investigated alloy, consisting of dispersive α phase particles present in β phase matrix. β phase facilitates plastic deformation and thus the formation of ductile fracture. α phase particles are mostly located in the observed dimples. Decohesion of the investigated samples occurs mostly at the boundaries of α phase particles and β phase matrix. α phase particles are non-uniformly distributed on the fracture surfaces, however, this distribution is quite uniform in crystallization dendrites. The quantity of α phase particles is smaller in interdendritic areas due to greater concentration of the elements stabilizing β phase. Moreover, these particles are mostly located on the boundaries of β phase. Such areas seem to be indicative of brittle rupture and were sporadically noticed on the fracture surfaces of the samples tested at highest tensile test speed.

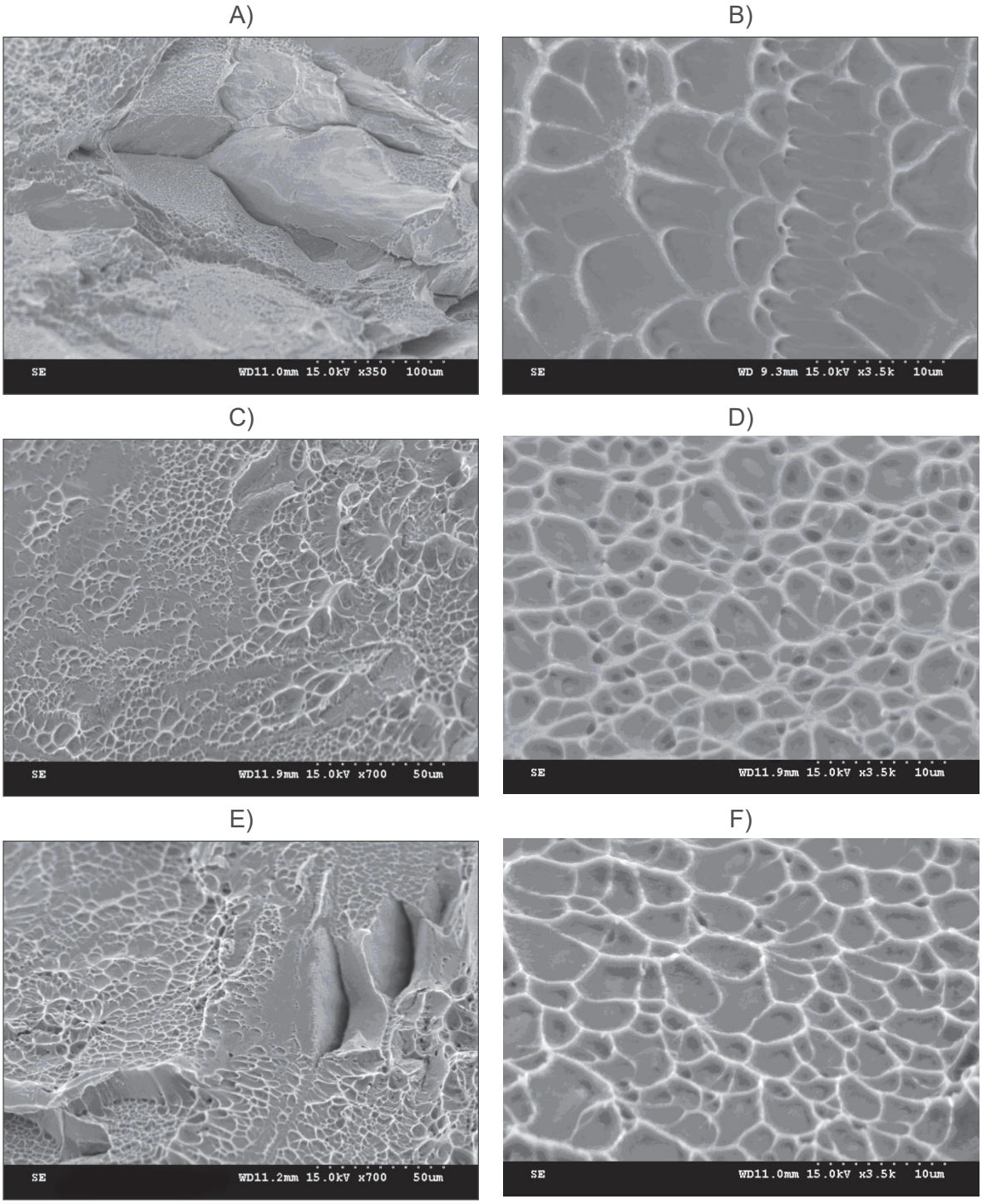


**Fig. 6** Tensile fracture surface of Ti-3Al-8V-6Cr-4Mo-4Zr alloy deformed at various testing speeds: A, B) 0.0001 $m \cdot s^{-1}$.; C, D) 0.1 $m \cdot s^{-1}$; E,F) 1 $m \cdot s^{-1}$

## CONCLUSIONS

Basing on the results of the performed research the following conclusions can be drawn:

The tensile tests performed on Ti-3Al-8V-6Cr-4Mo-4Zr alloy under dynamic conditions showed higher values of the fracture strength of the test samples in comparison to the fracture strength of the samples tested under quasi - static conditions.

An increase of the tensile test strain rate resulted in the fracture of the samples at lower value of the total strain.

The changes of the tensile tests strain rate from 0.0001 (quasi - static conditions) to 0.1 $m \cdot s^{-1}$ did not influence the elastic modulus of the investigated material, while increase of this value to 1.0 $m \cdot s^{-1}$ caused a slight decrease of the elastic modulus.

Most of the observed fracture surfaces exhibit dimples which are indicative of ductile rupture. Such nature of the fracture was observed in the case of all tested samples, regardless of tensile test speed.

The results of the performed investigations can be useful in the design of Ti-6Al-4V alloy structural parts operating under high strain rate conditions, in particular for aircraft or aerospace industry applications.

## ACKNOWLEDGEMENTS

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