MECHANICAL CHARACTERISTICS OF CoCrMo ALLOYS MANUFACTURED BY SELECTIVE LASER SINTERING TECHNOLOGY

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Abstract

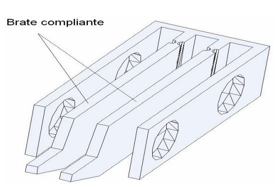
The aim of this paper is measurement of mechanical characteristics of CoCrMo parts. These are components of mechatronic assemblies, and were manufactured by using selective laser sintering technology. Our work follow two main objectives: manufacture of sample parts and associated mechanical tests in order to measure the material characteristics. Even if the materials produced by selective laser sintering are structural anisotropic, the experimental data within the same type of test had a relative low scattering.

Keywords: *CoCrMo alloy, mechanical tests, selective laser sintering.*

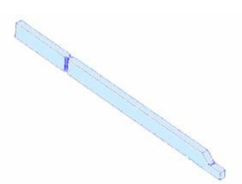
1. INTRODUCTION

The aim of this work is mechanical characteristics analysis of main drive element, which is component a manipulative device.

The movable part is made of two arms which perform the actuation force necessary for fixing and handling of manipulated objects. The arms are in fact two beams rigidly embed in support (Fig.1) and their main loading is flexion.



a.



b.

Fig.1. Device assembly (a) and actuator arm (b)

For estimation of manipulation technological parameters required, the mechanical properties of beam material were measure. The tests (traction and flexion) were performed by a universal testing machine Hounsfield-H10KT.

Due to the manufacturing process characteristics (Selective Laser Sintering) in which the part is obtained layer by layer the material structure has a certain degree of heterogeneity. This level of heterogeneity may be revealed by a significant variation of the material hardness along the longitudinal axis of the samples.

Parts (sample arms) tested were made of CoCrMo alloy. Chemical composition of cobalt chromium alloy (a CoCrMo superalloy trade named MP1) is shown in Table 1) [1]. The role of chromium in the alloy is corrosion prevention, while the molybdenum finishing the material structure.

Table 1. CoCr MP1 alloy chemical composition

The power type	Compozition	
Cobalt Crom MP1 (CoCrMo superalloy)	Co	60 - 65 %
	Cr	26 - 30 %
	Mo	5 - 7 %
	Si	max. 1,0 %
	Mn	max. 1,0 %
	Fe	max. 0,75 %
	C	max. 0,16 %
	Ni	max. 0,10 %

The rectangular samples tested with dimensions lxbxh (35x3x1mm) symbolized P1-P4, were fabricated by technological procedure mentioned above.

2. MATERIAL HARDNESS

CoCrMo alloy hardness tests are performed with a digital Rockwell hardness tester NAMICON (Fig.2) with diamond indenter and 1471N loading cell.

Fig.2. Rockwell hardness tester type NAMICON

On each side of samples with 35 mm length and 3 mm width, were carried out five measurements at 6 mm distance from each other. The means of measured values for two samples are shown in Table 2.

Table 2. The mean of hardness values measureared on both sides of P1 and P2 samples.

Sample	Average hardness [HRC]	Absolute maximum error	Relative maximum error [%]
P1	37.41	3.19	8.5
P2	37.94	4.24	11.17

The scattering of experimental data can have several sources:

- The material heterogeneity [2], because it comes from sintered powders;
- Errors due to Hardness Testers measurement accuracy;
- The material surface is relatively rough and can also has an influence on the hardness measured value [2];

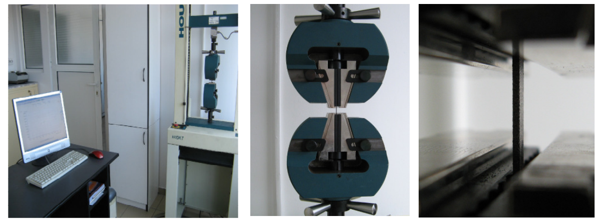
CoCrMo alloys with the material composition mentioned above shows in their structure even martensite, a hard constituent, which significantly increase the material hardness. The proportion of martensite is related on the chemical composition and the deformation degree of material (because the martensitic transformation can be induced by mechanical stress) [3].

The measured hardness of material before it is subjected to mechanical tests was around 37 HRC. After mechanical testing of samples, the material hardness has not increased significantly (37,41 HRC for sample P1 subjected to traction, respectively 37,94 HRC for sample P2 subjected to bending).

It can be concluded that, by applying the strain which is characteristic of each kind of test, there was not observed a significant amount of martensite formed which would have led to increased hardness (knowing that martensite is a hard constituent).

Hounsfield-H10KT traction testing machine (Fig.3.a) with 10.000 N load capacity can perform tests according to SR EN ISO 6892-1 - Metallic Materials. Traction test was carried out at ambient temperature and the initial dimensions of the samples were measured using a precision digital caliper.

The loading force is automatically measured by the force cell machine. In the same time is measured the absolute elongation of the sample (distance variation between the jaws). Because the manufactured samples have not a standard size (Fig.4), the sample fixation requires special attention (Fig. 3.b).



a b c

Fig.3. Hounsfield-H10KT test machine (a) sample holder (b), the sample detail (c)

The samples appearance before and after breakage is shown in figure 4.

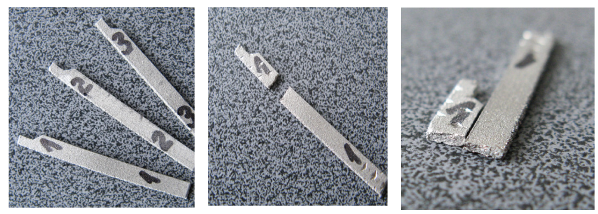


Fig.4. Tested samples

Experimental data taken with a data acquisition card are returned from the testing machine in a graphical form in loading force - absolute strain coordinate (Fig.5), and loading force - strain data pairs could be exported as .xls file.

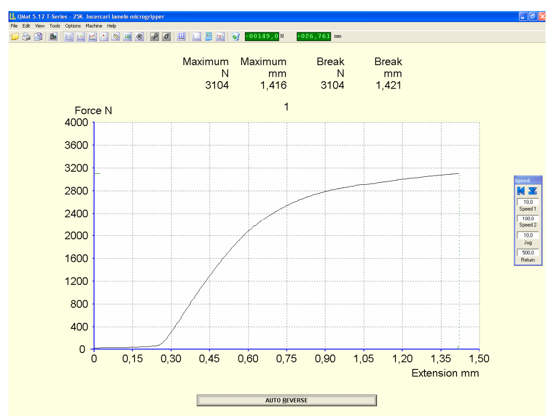


Fig.5. Traction test graph for CoCrMo sample (sample lenght 25 mm)

In order to estimate the modulus of elasticity (Young's modulus) from the real stress-strain curve, Microsoft Excel was used for numerical processing of data.

The test was performed for a jaw speed of 2 mm/min.

Because the sample has a constant section along the entire length, in order to perform the experiment without additional tension in the clamping sections, the test is carried out without preloading force.

Because the beginning of the test was a slip of the specimen in the jaw (curve shape illustrated in figure 5) for a correct estimate of modulus of elasticity, the curve characteristic points until absolute deformation to 0,25 mm are removed.

In figure 6 is the stress-strain sample P1 curve characteristic.

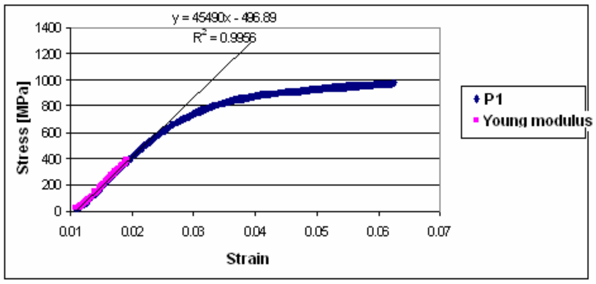


Fig.6. Stress-strain curve for CoCrMo sample

Ultimate tensile strength for CoCrMo specimen P1 is around 1000 MPa. After regression analysis of experimental data (shown graphically in Fig.7) were selected the pairs of points which are necessary for longitudinal elastic modulus estimation. As shown in figure 6 (slope of the equation which describe the liniar portion of the curve) and in figure 7 (the maximum value observed on the abscissa of regression curve), Young's modulus is E = 45490MPa.

Root-mean-square deviation for the curve domaine in which was measured modulus has a value close to 1 (R^2=0,9956), which shows a good correlation with experimental data. This good correlation is result of high sampling frequency and precision of measurement systems (force and displacement).

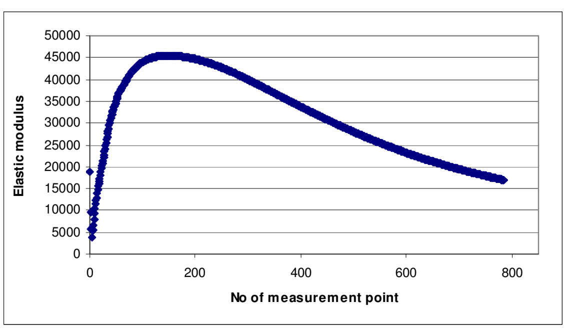


Fig.7. Regression curve of longitudinal elastic modulus

On the ordinate of the curve in Figure 7 are represented the elastic modulus values estimated by using LINEST function of Excel software, that calculates the angular coefficient of the linearized curve. Each point on the graph has as signification the value of elastic modulus calculated for a number of points between two and the maximum number of measurement points.

This measurements are a preliminary set of material characteristics determination. Next step in order to estimate the complet mechanical behavior of the arms as a component of a complex mechanism, is bending test.

4. BENDING TEST

The bending test perform was also non-standard.
The sample, a cantilever beam, is subjected to bending in the free end, as shown in (Fig. 8). Because the sample has a lower size as a standard one, it was not possible classical bending tests (three or four points bending test).

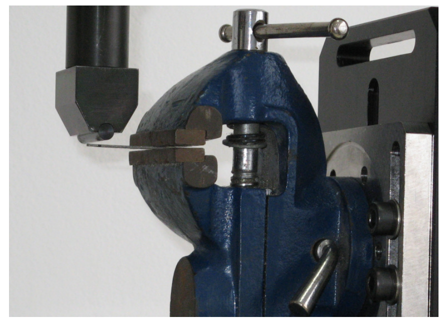


Fig.8. Sample holder of cantilever beam and aplication system of bending force

During the test, were measured the elastic deflection of cantilever beam (displacement of sample) and bending force. Graphical representation of dependence between this two parameters is shown in figure 9.

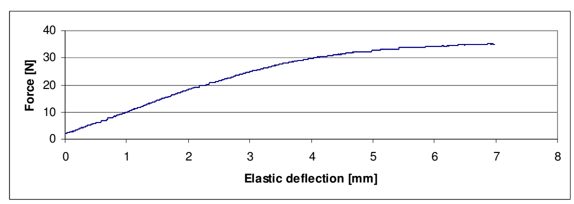


Fig.9. Elastic deflection specimen vs. applied force

Ecuation which relates cantilever end deflection *u* to applied force *F* is:

$$u = \frac{F \cdot l^3}{3 \cdot E \cdot I_z} \qquad (1)$$

where:

u - elastic deflection (mm);
F - force (N);
l - length of the beam (25 mm);
E – Elastic modulus (MPa);
I_z – area moment of inertia (mm^4).

In order to select the range of data relevant to estimate the elastic modulus was performed regression analysis of the experimental data (Fig.10).

With the exception of deflection force, all other parameters in equation (1) are constant and dependent on the sample geometry (I_z and l), or the material elastic properties (E).

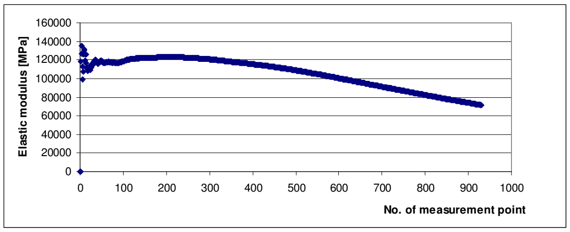


Fig.10. Regression curve of longitudinal elastic modulus

Due to the linear variation between force and elastic deflection of cantilever end, as shown in figure 11, the angular coefficient of the tangent to the curve has as signification the longitudinal elastic modulus.

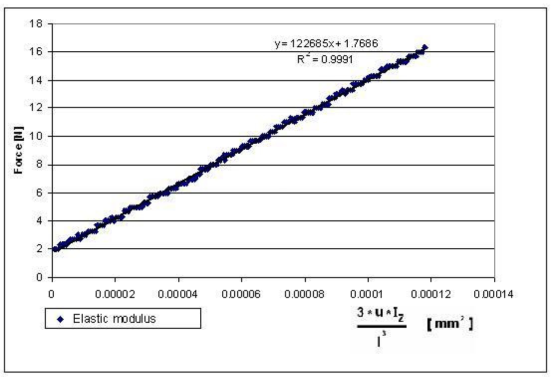


Fig.11. Longitudinal elastic modulus estimation

The elastic modulus estimated by using bending test has value of 122,68 GPa, about three times higher than that obtained by using tensile test.

Because the elastic modulus of material reported by manufacturer has a higher value (220 GPa) than that measured, it is assumed that the estimation by using the tensile test was strongly affected by measurement errors due mainly of sliding sample in clamping system.

In this case, by using bending test was obtained a more accurate value of elastic modulus.

CONCLUSIONS

The tested part manufactured from (CoCrMo alloy) by using selective laser sintering is the main component for actuation of a micromanipulator.
In service the part is a cantilever beam subjected mainly to bending stress.

In order to test the mechanical characteristics have been made non-standard size specimens due to high cost involved by fabrication of standard specimens.

The hardness values 37-38 HRC measured after applied stress, are so close to those measured before traction and bending. This phenomena can be explained if the rate of martensite induced stress occured during the mechanical tests is insignificant.

The value of tensile strength hasn't exceed 1000 MPa, value with arround 10% lower than that reported by the powder supplier.

Despite of the samples were unstandard, it can be estimated strength characteristics with reasonable accuracy, but in case of elastic characteristics, innapropriate samples could slide in the testing machine jaws.

If isn't use an extensometer fixed on the sample in traction test, and strain is measured as distance between jaws, the strain values could be bigger than real ones and the elastic modulus subsequently estimated in these condition is lower.

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