ETIKUM 2023

INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, DECEMBER 7-9, 2023

**Kostić, S., Kočović, V., Vasiljević, S., Miletić, S., Jovanović Pešić, Ž., Džunić, D.**

# TENSILE TESTING OF ELECTROCHEMICALLY MACHINED SPECIMENS

***Abstract:*** *The complexity of the procedure of specimens is primarily contained in the technological problems of making long thin samples with a circular cross section. Specimens for a small laboratory tensile testing device (SLTTD) are of non-standard shapes. Based on previous research, it was concluded that by reducing the cross-sectional area and increasing the original gauge length of specimen, the measurement accuracy increases. Such specimens cannot be made by conventional methods, but non-conventional one, such as electrochemical machining (ECM). Specimens made by ECM were tested on a SLTTD, and the obtained results were compared with test results available in the literature.*

***Key words:*** *Tensile testing, Electrochemical machining, Small laboratory tensile testing device*

## 1. INTRODUCTION

In modern engineering practice, materials research and development play a key role in achieving high standards of safety, reliability and efficiency in various industries. One of the most important aspects of this research is related to the improvement of the mechanical properties of metals, since metals are often used for constructions subjected to significant mechanical loads.

ECM of metals is a complex discipline that connects the principles of chemistry and electrochemistry with materials engineering. This method allows controlled manipulation of the surface properties of metals, including hardness, strength, corrosion resistance and other mechanical properties, using ECM such as electrodeposition, electropolishing, anodic oxidation and the like. ECM has proven particularly useful in tensile testing, as it allows engineers and researchers to precisely adapt the properties of metals to meet the specific needs of different applications.

By using an electrode for the controlled introduction of electric current into the electrolyte solution of the metal, an electrode reaction is caused on the surface of the metal. After electrochemical treatment, the sample can be further prepared, for example, by grinding and polishing, in order to achieve the desired surface roughness and dimensional accuracy [1].

With the use of new materials of higher strength in the automotive, aerospace and manufacturing industries, difficulties arise with cutting by conventional machining processes, so the use of non-conventional machining processes is switched to. The work of Liu et al. (2023) provides a detailed overview of the influence of various process parameters on performance measures in the ECM [2].

In the work of Kumar et al. (2023) conclude that the unique feature of the toolless electrochemical jet machining is suitable for the finishing of additive manufacturing (AM) parts. Surface defects and irregularities on complex parts present challenges during processing with conventional processes [3].

Another review paper by Gautam et al. (2022) presents a study of electrical discharge machining, wire electrical discharge, and electrochemical machining. The paper provides optimal parameters for the above processes that can help increase production in various industries [4].

This scientific work aims to research and analyze the ECM of metal specimens with the intention of obtaining specimens with small cross-sections and relatively large original gauge lengths, which are difficult to obtain with conventional processing methods. The obtained samples were tested on a SLTTD [5], and the obtained results are comparative with the results presented in the literature. Through this analysis, this work contributes to a better understanding and control of the mechanical properties of metals, which has the potential to improve the performance and durability of metal structures in a wide range of engineering applications.

## 2. RESEARCH METHODOLOGY

The problems of obtaining the accurate values of the mechanical characteristics of the tensile devices arise due to a large number of factors.

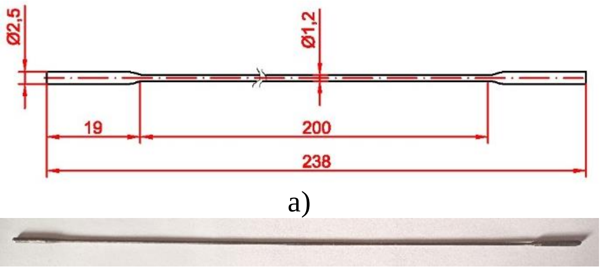
Using a SLTTD for tensile testing of materials, and based on measuring the modulus of elasticity of the material as the most sensitive characteristic, Kostić et al. (2022) came to the conclusion that the specimens must be as small as possible in cross-section and as large as possible in original gauge length [5]. The described shape of the specimens guarantees satisfactory measurement accuracy without the use of an extensometer. This conclusion was reached by analyzing the errors of the measuring system, which are primarily the result of elastic deformation of the functional parts of the device structure due to the action of the tension force during the tensile testing, such as the clamping system. Non-standard specimens with a circular cross-section were made by ECM.

Faraday's law, which connects the amount of metal dissolved during electrolysis and the strength and time of current flow between two electrodes immersed in the electrolyte, represents the basis of electrochemical processing [6]. Controlled removal of material is performed by electrolysis, with the workpiece representing the anode (+) and the tool the cathode (-), Figure 1.

Fig. 1. ESM of a circular cross-section specimen with non-standard dimensions

The shape and geometric characteristics of the specimen, as well as a photo of the machined specimen, are given in Figure 2. The original gauge length of the specimen is 200 mm, and the diameter is 1.5 mm. The investigation was conducted on specimen made of non-alloy quality structural steel E360 whose chemical composition is: ≤ 0.045% P, ≤ 0.045% S, ≤0.012% N. The mechanical and physical characteristics of structural steel E360 are: Elastic modulus=190 GPa, hardness=210 HB, tensile strength=690-900 MPa, yield strength=350 MPa, Poisson ratio=0.29 and density=7.9 g/cm$^3$.

The specimen shown in Figure 2 is made of semi-finished products with a diameter of 2.5 mm. The thickening of the specimen was achieved by placing an insulating layer in those zones, in order to prevent the removal of material on the parts for receiving the specimen. The ECM process was carried out in a saline solution under the action of a DC voltage of 12V without relative movement of the electrodes. This voltage value was chosen after a preliminary test which showed that the specimens obtained under these conditions have the least dimensional and geometrical errors. The manufacturing process is slow but guarantees the required quality.



a)

b)

Fig. 2. Specimen a) shape and geometric characteristics and b) photograph

By increasing the voltage, the electrochemical process is accelerated, but dimensional and geometrical defects increase, Figure 3.

Fig. 3. Dimensional errors and surface defects of specimen made by ECM using 48V voltage

A high voltage value leads to a violent reaction, which is followed by a sudden decrease in diameter. The reduced diameter is intense and amounts to approximately 0.1 mm/min. The intensity of material removal in the first minute of processing is shown in Figure 4. The figure shows the process of making a brass specimen. Thus, the considered method provides the possibility of fine processing of all metal materials.

Depending on the processed material, the color of the electrolyte after processing will also differ, which is caused by the remains of the processed material, as shown in Figure 5.

The authors of this paper paid special attention to the clamping system of specimen, in order to minimize measurement errors. The specimen is freely supported in the clamping grips, and after that the bushing are pulled on and the receiving zone is tightened with a screw.

In this way, the alignment of the left and right clamping grips and the balance of forces in the directions normal to the tension axis are ensured, which eliminates the deformation of the specimen that occurs when the specimen is grounded without clamping, Figure 6.

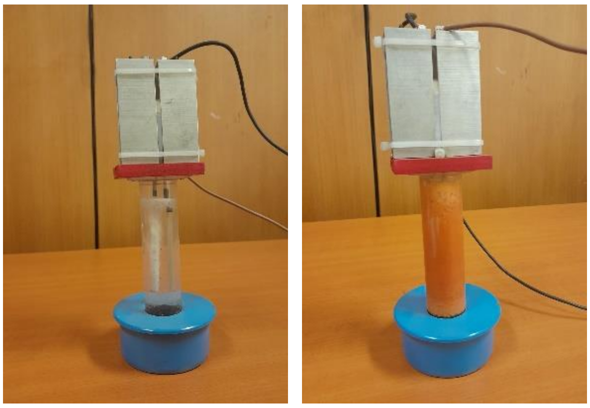
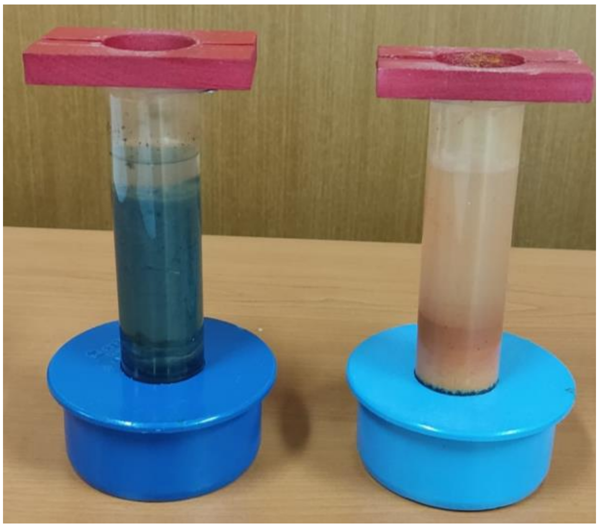


Fig. 4. Intensity of material removal in the first minute of processing by applying a voltage of 48V in the case of making a brass specimen



a) b)

Fig. 5. The appearance of the electrolyte after processing depends on the type of processed material a) steel; b) brass

The work is restricted to tests performed at ambient temperatures 23±2°C, with a digital acquisition of load and displacement. The tests are assumed to run continuously without interruptions on specimens that have uniform gauge lengths, and the procedure is restricted to tests performed under axial loading conditions. The experiments were conducted in controlled microclimatic conditions according to the standard EN ISO 6892-1:2019 [6].

SLTTD has load cell 2 kN nom. capacity, the elongation is measured by moving the clamping grip of the SLTTD. The diameter of specimen are measured with an accuracy of ±10 µm.

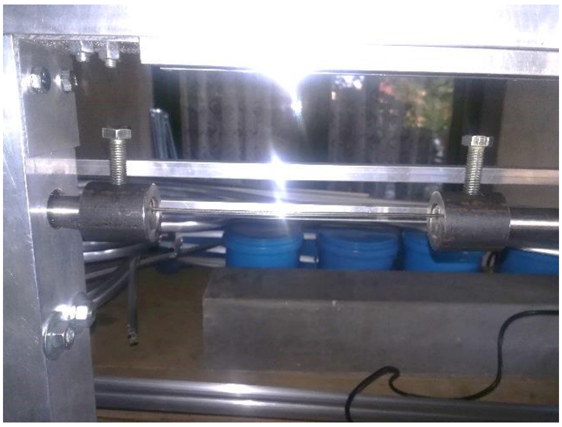


Fig. 6. Positioning specimen in clamping system on a SLTTD before starting the test

## 3. TEST RESULTS

The stress-strain diagram, which was obtained after tensile testing the E360 steel material on a SLTTD, is given in Figure 7.

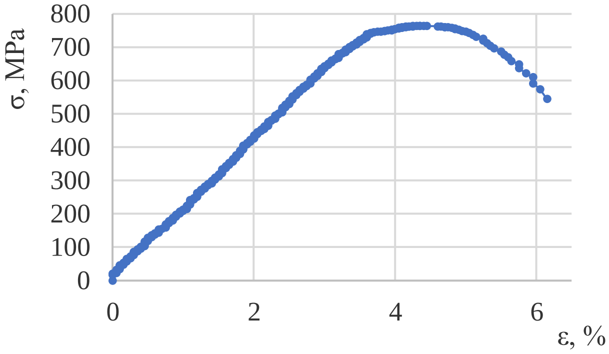


Fig. 7. Stress-strain diagram of the tested E360 steel material specimen

The diagram clearly shows the tensile strength value of 764.2 MPa, which represents a value that corresponds to the range of reference values given in the literature [8]. The fracture elongation is 6.15%, which also corresponds to the data available in the literature, Figure 7.

SLTTD is equipped with software, which performs automatic processing of collected data during testing [9]. In this way, diagrams of real stresses and deformations can be obtained immediately after the test, because during the test the cross-section changes, first by the appearance of uniform plastic deformations, and then by the formation of necks on specimen. After reaching the maximum force, uneven plastic deformations occur, which cause the formation of a narrowing of the cross-section at the point where the specimen will break. The diagram of the dependence of the real cross-sectional area of the specimen on the real stress during the test for the material steel E360 is shown in Figure 8.

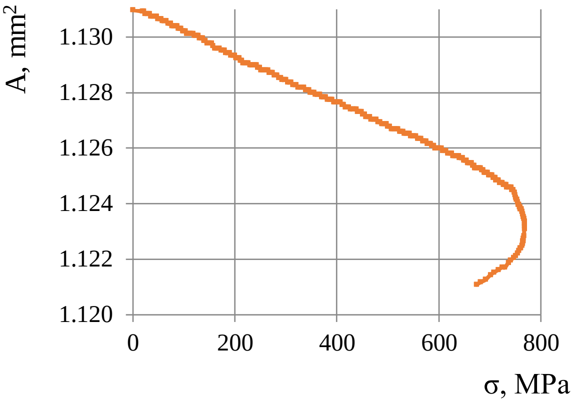


Fig. 8. Diagram real cross-sectional area of the specimen – real stress, of steel E360

The diagram in Figure 8 clearly shows the contraction of the cross section, which corresponds to the characteristics of the tested material. Small values of cross-section contraction, as well as deformation values shown in Figure 7, clearly indicate the properties of the tested steel.

## 4. CONCLUSION

Today's application of ECM most often focuses on the production of parts with complex shapes and materials that are difficult to process, and the precise shaping of material parts is a challenge for conventional processing methods. After the ECM treatment, there are no residual surface stresses, thus providing the material with better stability and reducing the risk of stress damage. This aspect makes ECM an attractive option in many industries that require a high degree of precision and control of the mechanical properties of materials.

Tensile testing specimens of non-standard shapes can be made by ECM. A comparison of tensile test results obtained on a SLTTD with test results available in the literature supports this claim.

Future research in this area will go in the direction of optimizing all parameters of the ECM of samples, such as electrolyte quality and properties, current strength, processing time, material, geometry and position of electrode, electrolyte flow. The precise setting of the parameters is crucial for achieving the desired characteristics of the material after electrochemical processing. Variations in these parameters can result in different properties of the machined material, including surface roughness, thickness of material removed, and other desired characteristics.

## 5. REFERENCES

[1] Fourdeux, A., Wronski, A., *New electrolytic method for cutting and shaping metal specimens*, British Journal of Applied Physics, 14, 4, pp. 218-220, 1963.
[2] Liu, S., Thangamani, G., Thangaraj, M., *Recent trends on electro chemical machining process of metallic materials: a review*, Archiv.Civ.Mech.Eng, 23, 158, 2023.
[3] Kumar, P., Dixit, P., Chaudhary, B., Jain, N.K., *Surface finishing of an additively manufactured part using electrochemical jet machining*, Materials Today Communications, 35, 105581, 2023.
[4] Gautam, N., Goyal, A., Sharma, S., Oza, A., Kumar, R., *Study of various optimization techniques for electric discharge machining and electrochemical machining processes*, Materials Today: Proceedings, 57, 2, pp 615-621, 2022.
[5] Kostić, S., Miljojković, J., Šimunović, G., Vukelić, Đ., Tadić, B., *Uncertainty in the determination of elastic modulus by tensile testing*, Engineering Science and Technology, an International Journal, 25, 100998, 2022.
[6] Lazić M.: *Nekonvencionalni postupci obrade*, Naučna knjiga, Beograd, 1990
[7] EN ISO 6892-1:2019: Metallic materials - Tensile testing - Part 1: Method of test at room temperature, Europian Committee for Standardization, 2019.
[8] ASM Atlas of Stress-Strain Curves, Second edition. ISBN:0-87170-739-X, 2002.
[9] Kostić, S., Košarac, A., Luković, V., Miljojković, J., *Theory Reviews - Hardware and Software Support for Testing Material on Specimens of the Small Cross Section*, Tribology in Industry, 41, pp. 109-114, 2019.

***Authors:*** **Prof. of App. Studies. dr Sonja Kostić, Teaching Assis. Saša Vasiljević,** Academy of Professional Studies Šumadija, Department in Kragujevac, Kosovska 8, Kragujevac, Serbia**.**
E-mail: skostic@asss.edu.rs
svasiljevic@asss.edu.rs

**Assis. prof. dr Vladimir Kočović, MEng. Stefan Miletić, MEng. Živana Jovanović Pešić, Assoc. prof. dr Dragan Džunić,** University of Kragujevac, Faculty of Engineering, Sestre Janjić street, no. 6 - 34000 Kragujevac, Serbia.
E-mail: vladimir.kocovic@kg.ac.rs
stefan96miletic.finkg@gmail.com
zixi90@gmail.com
dzuna@kg.ac.rs