



University of Zenica
FACULTY OF METALLURGY AND
TECHNOLOGY
Bosnia and Herzegovina



Univerzitet u Zenici
METALURŠKO-TEHNOLOŠKI FAKULTET
Bosna i Hercegovina

**14th Scientific - Research Symposium
with International Participation**

**METALLIC AND NONMETALLIC MATERIALS
production – properties – application**

**XIV Naučno - stručni simpozijum
sa međunarodnim učesćem**

**METALNI I NEMETALNI MATERIJALI
proizvodnja – osobine – primjena**

**BOOK OF ABSTRACTS with electronic edition of Proceedings
KNJIGA ABSTRAKTA sa elektronskim izdanjem Zbornika radova**



Zenica, Bosnia and Herzegovina, 27th-28th April 2023
Zenica, Bosna i Hercegovina, 27-28. april 2023.

EDITOR/UREDNIK

Dr Farzet Bikić

PUBLISHER/IZDAVAČ

Univerzitet u Zenici

Organizaciona jedinica Metalurško-tehnološki fakultet

Travnička cesta 1, 72000 Zenica

Tel: ++

387 401 831, 402 832, Fax: ++ 387 406 903

TECHNICAL ASSISTANCE AND DTP

KOMPJUTERSKA OBRADA TEKSTA

Amila Krnjić

Zahida Begović

Dejana Kasapović

Lamija Sušić

PRINTED BY/ŠTAMPA

ŠTAMPARIJA FOJNICA D.D.

ISSUE/TIRAŽ: 100 copies/primjeraka

ORGANIZING COMMITTEE/ORGANIZACIONI ODBOR

Dr Farzet Bikić, president

Dr Jusuf Duraković
Dr Ilhan Bušatlić
Dr Adnan Mujkanović
Dr Hasan Avdušinović
Mr Dejana Kasapović
Mr Amna Karić, secretary
Lamija Sušić, dipl. Ing.

INTERNATIONAL SCIENTIFIC/RESEARCH COMMITTEE/NAUČNI ODBOR

Dr Anžel Ivan, SI	Dr Jovanović Marina, BA
Dr Avdušinović Hasan, BA	Dr Komatina Mirko, RS
Dr Balanović Ljubiša, RS	Dr Kosec Borut, SI
Dr Begić-Hajdarević Đerzija, BA	Dr Korać Fehim, BA
Dr Berberović Edin, BA	Dr Krolo Petar, RH
Dr Bikić Farzet, BA	Dr Lamut Jakob, SI
Dr Bizjak Milan, SI	Dr Lazić Dragica, BA
Dr Bogdanović Grozdanka, RS	Dr Lemeš Samir, BA
Dr Burzić Zijah, RS	Dr Mamuzić Ilija, HR
Dr Bušatlić Ilhan, BA	Dr Medved Jožef, SI
Dr Bušatlić Nadira BA	Dr Merdić Nevzet, BA
Dr Chumbley Scott, US	Dr Mirjanić Dragoljub, BA
Dr Ćubela Diana, BA	Dr Mujkanović Adnan, BA
Dr Ćatić Sead, BA	Dr Nagode Aleš, SI
Dr Dabić Pero, HR	Dr Oruč Mirsada, BA
Dr Delijić Kemal, CG	Dr Pašić Sead, BA
Dr Dolić Natalija, HR	Dr Perušić Mitar, BA
Dr Dolinžek Slavko, SI	Dr Ranogajec Jonjaua, RS
Dr Duraković Jusuf, BA	Dr Rustempašić Neriman, BA
Dr Džubur Žana, BA	Dr Salihović Senaid, BA
Dr Džonlagić Nusreta, BA	Dr Senk Dieter, DE
Dr Ekinović Sabahudin, BA	Dr Spužić Sead, AU
Dr Fidančevska Emilija, MK	Dr Srbić Vladimir, RS
Dr Gigović-Gekić Almaida, BA	Dr Stanojlović Rodoljub, RS
Dr Gojić Mirko, HR	Dr Stuhli Vedran, BA
Dr Grubešić Ivana, BA	Dr Suljagić Jasmin, BA
Dr Hadžikadunić Fuad, BA	Dr Sunulahpašić Raza, BA
Dr Halilović Azra, BA	Dr Štrajčić Jovan, BA
Dr Hamedović Safet, BA	Dr Štrbac Nada, RS
Dr Haračić Nedžad, BA	Dr Volkov-Husović Tatjana, RS
Dr Hessling Goetz, DE	Dr Vučenović Siniša, BA
Dr Herenda Safija, BA	Dr Vukojević Nedeljko, BA
Dr Holger Frenz, DE	Dr Vukojević-Medvidović Nediljka, HR
Dr Imamović Aida, BA	Dr Zelić Jelica, HR
Dr Imamović Nusret, BA	Dr Zlokolica Miodrag, RS
Dr Ivanković Hrvoje, HR	Dr Zovko-Brodarac Zdenka, HR
Dr Iličković Zoran, BA	Dr Žero Sabina, BA
Dr Janačković Đorđe, RS	Dr Živković Živan, RS

14(2023), No.14
ISSN2566-4344

14th Scientific – Research Symposium
with International Participation

METALLIC AND NONMETALLIC MATERIALS
production – properties – application

PROCEEDINGS

Zenica, B&H, April 27th 2023

CONTENTS

page

KEYNOTES PAPERS

- 1. PYROPHYLLITE-MODIFIED CARBON PASTE ELECTRODE FOR CARBENDAZIM DETECTION IN WATER AND FOOD**
J. Grbović Novaković, A. Mitrović Rajić, K. Tošić, S. Mijaković,
S. Milošević Govedarević, A. Vujačić Nikezić, B. Paskaš Mamula, J. Kustura,
E. Kurtanović, B. Halilhodžić 1
- 2. FERTILIZER BASED ON PYROPHYLLITE IN ACCORDANCE WITH THE REGULATION EU 2019/1009**
M. J. Adamović, J. Kustura, E. Kurtanović, B. Halilhodžić, A. Hodžić,
M. Harbinja, M. D. Stojanović..... 10
- 3. REMOVAL OF POTENTIALLY TOXIC METAL IONS FROM AQUEOUS SOLUTION BY ADSORPTION ON MECHANOCHEMICALLY ACTIVATED PYROPHYLLITE**
T. M. Trtić-Petrović, D. Lazarević, I. Pušica, J. Kustura, B. Halilhodžić,
E. Kurtanović, A. Teletović, A. Hodžić, M. Harbinja..... 17
- 4. CHALLENGES IN THE APPLICATION OF THE LAW ON SAFETY AT WORK IN FBiH**
M. Todorović, A. Helvida, S. Živković 25

METALLIC MATERIALS

- 1. Analysis of production method and stabilizing agent on structure of aluminum metal foams**
K. Grgić, I. Čulum, B. Lela, J. Krolo, S. Jozić..... 37
- 2. Manufacturing and characterization of Ti6Al4V alloy by selective laser melting**
M. Zorc, A. Nagode, M. Pogačar, B. Karpe, B. Kosec, M. Bizjak..... 43
- 3. Adsorption of Cu(II) ions by means of foundry waste**
A. Štrkalj, Z. Glavaš 51
- 4. Hydrogenation process of titanium alloy for biomedical purposes**
A. Imamović, Š. Žuna, M. Oruč, E. Hadžibulić 58
- 5. Effect of particle shape and size of copper powders on the properties of sintered parts**
I. Marković, D. Manasijević, Lj. Balanović, M. Mitrović, U. Stamenković,
S. Trujić 64
- 6. Thermal and microstructural analysis of the low-melting Bi–In–Sn ternary alloys**
Lj. Balanović, D. Manasijević, I. Marković, M. Gorgievski,
U. Stamenković, D. Milkić..... 73

7. Relationship of microstructural transformations in austempered nodular cast with microhardness values <i>A. Burić, B. Fakić, E. Horoz, H. Avdušinović, R. Sunulahpašić</i>	83
8. Effect of mixing of cooling media on microstructure and hardness of steel 23MnB4 <i>A. Gigović-Gekić, H. Avdušinović, B. Muminović, A. Hodžić</i>	91
9. The influence of alloying elements to cast iron microstructure <i>A. Henjaković, H. Avdušinović, A. Muslić</i>	98
10. Characteristics of the microstructure and grain size of S690QL steel in the hardened and tempered state <i>M. Oruč, M. Rimac, A. Imamović, A. Gigović-Gekić</i> .	105
11. Properties of austenite stainless steel X8CrNiS18-9 microalloyed with tellurium <i>D. Mujagić, A. Imamović, M. Hadžalić</i>	111
12. Microstructural degradation of boiler headers steels under long term exposure to high temperature <i>A. Husika, B. Fakić, M. Rimac</i>	116
13. The influence of heat treatment on microstructure and thermal properties of C45 tool steel <i>U. Stamenković, I. Marković, S. Mladenović, D. Manasijević, Lj. Balanović, M. Nedeljković, J. Božinović, A. Kovačević</i>	125
14. Thermal properties of copper base shape memory alloy <i>B. Kosec, B. Karpe, A. Nagode, M. Bizjak, L. Vrsalović, D. Čubela, M. Gojić, I. Ivanić, S. Kožuh</i>	133
15. Effect grain size of S690QL steel on impact fracture at low temperature <i>M. Oruč, G. Kosec, A. Imamović, R. Sunulahpašić</i>	139
16. Application of the BAS EN ISO 1463:2022 standard in the characterization of pipe materials for thermal energy plants <i>B. Fakić, A. Burić, E. Horoz</i>	145
17. Contribution to mechanical properties assessment of spherical cylindrical head shells made by the incremental sheet forming <i>M. Hadžalić, R. Sunulahpašić, Z. Ištvančić</i>	149
18. NDT testing and determination of the state of the materials of the headers of the boiler unit 5 in the Thermal Power Plant Kakanj <i>A. Husika, B. Fakić, M. Rimac</i>	158
19. The effect of cysteine on the corrosion characteristics of bioalloy <i>S. Herenda, M. Begović, E. Hasković, V. Asanović</i>	167

20. Electrical properties of granular metals <i>M. Đekić, A. Karić, A. Salčinović Fetić, M. Baždar, B. Husković, D. Dujak, D. Čubela</i>	172
21. Investigation of cutting conditions influence on surface roughness during MQL machining of steel <i>T. Gazić, S. Ekinović, E. Begović, I. Plančić</i>	179
22. Some aspects of a metallurgy consulting in the industrial transition of B&H <i>F. Uzunović</i>	186

NONMETALLIC MATERIALS

1. Partial replacement of cement with calcined clays from central Bosnia <i>M. Jovanović, A. Mujkanović, N. Bušatlić, N. Haračić, A. Čaušević</i>	199
2. Possibility of production of metallurgical cement type CEM III/A 42.5N in Cement plant Kakanj <i>N. Merdić, N. Haračić, I. Bušatlić, N. Bušatlić, A. Mujkanović</i>	209
3. Development of new cement type CEM II/C-M according to EN 197-5 <i>N. Haračić, N. Merdić, I. Bušatlić, N. Bušatlić</i>	214
4. Strength development of concrete containing ground granulated blast furnace slag from ArcelorMittal Zenica as a partial cement replacement <i>A. Mujkanović, A. Bitić, M. Jovanović, N. Bušatlić, N. Merdić, A. Zahirović</i>	218
5. Calculation of thermal conductivity for crystalline nanostructures <i>S. M. Vučenović, J. P. Šetrajčić</i>	226
6. Charge carriers states in a model of CuO superconductive ceramics <i>J. P. Šetrajčić, S. M. Vučenović</i>	233
7. Catecholase activity and substituent effect of new homoleptic copper(II) chalcone complexes <i>S. Hadžalić, I. Osmanković, A. Zahirović</i>	241

ENVIRONMENT PROTECTION AND SUSTAINABLE DEVELOPMENT

1. Pyrophyllite as an ecological mineral of the future <i>J. Kustura, B. Halilhodžić, E. Kurtanović, K. Kozlo, A. Čizmić, A. Teletović, A. Hodžić, M. Harbinja</i>	253
2. Removal of heavy metals from landfill leach water using pyrophyllite as adsorbent <i>J. Kustura, B. Halilhodžić, E. Kurtanović, A. Čizmić, K. Kozlo, A. Teletović, A. Hodžić, M. Harbinja</i>	264
3. Heavy metal concentrations in surface water and sediment from Drina river, B&H <i>A. Bilajac, S. Žero, A. Karadža</i>	274

4. The long-term impact of heavy metals from Bosna river to human health <i>A. Šapčanin, F. Bikić.....</i>	<i>280</i>
5. Influence of current density on leachate treatment efficiency by electrocoagulation with zeolite addition <i>N. Vukojević Medvidović, L. Vrsalović, S. Svilović, M. Cestarić.</i>	<i>286</i>
6. Study of interactions between metal ions and crown ethers in liquid organic membrane systems <i>E. Bjelić, J. Suljagić, M. Suljkanović.....</i>	<i>293</i>
7. Rutin analysis by high-resolution liquid chromatography on reverse phases in raspberry flower extract (<i>Rubus idaeus L.</i>) <i>D. Kasapović, F. Bikić.....</i>	<i>299</i>
8. Characteristics of vacuum distillation fractions depending on the characteristics of the input hydrocracked base oil raw material of the Modriča Oil Refinery <i>A. Halilović, I. Bušatlić, Š. Botonjić, N. Bušatlić, E. Zolotić.....</i>	<i>304</i>
9. The influence of the heating value of coals from Coal Mine „Gračanica“ d.o.o. Gornji Vakuf on quality of coal as energy source in energy production <i>A. Halilović, Š. Botonjić, A. Krnjić, L. Sušić.</i>	<i>312</i>
10. The measures of energy efficiency in Natron-Hayat Maglaj <i>N. Imamović, A. Čamić, H. Lepić.</i>	<i>320</i>
11. Screening of particulate matter in urban area of Sarajevo <i>A. Šapčanin, A. Hasanović, F. Bikić.....</i>	<i>326</i>
12. Analysis of the origin of air pollution in the area Zenica-Doboj canton <i>V. Birdahić, M. Šišić, N. Imamović, H. Prčanović, M. Duraković.....</i>	<i>335</i>
13. Research of the possibility of using the heat generated in the aerobic biodegradation procedure <i>M. Šišić, F. Bikić, V. Birdahić, S. Beganović, M. Duraković.....</i>	<i>342</i>
14. The role of wood-based products in sustainable development <i>P. Čurić, J. Obranković, A. Pirc Barčić.....</i>	<i>349</i>

EFFECT OF PARTICLE SHAPE AND SIZE OF COPPER POWDERS ON THE PROPERTIES OF SINTERED PARTS

Ivana Marković, Dragan Manasijević, Ljubiša Balanović, Uroš Stamenković,
Milijana Mitrović

University of Belgrade, Technical Faculty in Bor
Bor, Serbia

Stevan Trujić

HBIS Group Serbia Iron & Steel
Smederevo, Serbia

Keywords: electrolytic powders, water-atomized powders, sintering

ABSTRACT

The particle shape and size of the starting powders represent the most important physical properties, on which the quality of the compacts and final sintered products depends. Two types of powder were analyzed in the paper - electrolytic copper powder with a dendritic particle shape and water-atomized copper powder with an irregular particle shape. The starting powders were sieved through a sieve system with openings of 45 μm , 80 μm , and 120 μm . The characterization of the obtained fractions of both powders was performed by determining the shape and dimensions of the particles using SEM microscopy in combination with ImageJ software, and the apparent density and flow rate were determined using the Hall flowmeter funnel. Pressing of each powder fraction was done using a pressure of 600 MPa. The compacts were further sintered at 1000°C for 2 hours to obtain the final sintered parts. After sintering, their density, hardness, and electrical conductivity were determined and their microstructure was analyzed. The results indicate a great influence of the characteristics of the starting powders on the properties of the final parts obtained by the powder metallurgy route. The particle shape of the powders had a more pronounced influence compared to the particle size.

1. INTRODUCTION

The powder metallurgy (PM) route includes obtaining the final products through compact the starting powders and sintering them under controlled conditions. The main disadvantage of the classical PM process is the impossibility of achieving a full density of final products, due to their porosity, and that is why the mechanical properties of sintered parts are lower [1,2]. Properties of sintered parts depend on the parameters such as characteristics of the starting powders, compaction pressure, sintering temperature and time, etc. If the compaction pressure, sintering temperature, and time are higher, the density is superior, and the porosity is lower. Mechanical and electrical properties are also dependent on the density and porosity, therefore, they increase with an increase in compaction pressure, sintering temperature, and time, but all this increases the process cost [3].

In addition to the process parameters, the particle shape and size have a great influence on all operations during obtaining parts using the PM route and on the quality of the final sintered products. The particle shape has a large effect on the contacts between particles and therefore has a significant influence on their behavior during pressing and sintering. Generally, the compacts obtained from coarse powder particles have a higher density compared with the compacts from fine powders [4].

To obtain the required properties in the final sintered parts, a suitable combination of process parameters is required [5,6]. This paper presents the effects of particle shape and size of the starting copper powders, on the properties of powders, green compacts, and sintered samples. In the case of powders, the evaluated properties were apparent density and flow rate. In green compacts, density was evaluated, and in sintered samples hardness, electrical conductivity, and microstructure of PM parts were discussed. To obtain samples with different average particle sizes, water-atomized and electrolytic copper powders were sieved and separated with sieves with openings of 45 μm , 80 μm , and 120 μm .

2. EXPERIMENTAL PART

Water-atomized copper powder (supplied by Centrochem) with an irregular particle shape and electrolytic copper powder (supplied by Pometon) with a dendritic particle shape were used as starting materials. Commercial powders were sieved to obtain fractions with a narrow powder particle size distribution (in the range of about 40 μm). The powders were sieved on sieves with openings of 45 μm , 80 μm , and 120 μm . In this way, three fractions were obtained: - 45 μm , + 45 μm - 80 μm , and + 80 μm - 120 μm . The powder's designations are given in Table 1. The first letter in the designations indicates whether the powder was obtained by water-atomization (A) or by electrolytic method (E). Other letters indicate the range of particle sizes in that powder: very fine (VF) with particles below 45 μm , fine (F) with particles from 45 μm to 80 μm , and medium (M) with particles from 80 μm to 120 μm . This classification is based on the paper [7].

Table 1. The powder's/sample's designation

Fractions	Atomized powders	Electrolytic powders
- 45	A-VF (Atomized - Very Fine)	E-VF (Electrolytic - Very Fine)
+ 45-80	A-F (Atomized - Fine)	E-F (Electrolytic - Fine)
+ 80-120	A-M (Atomized - Medium)	E-M (Electrolytic - Medium)

The characterization of the powders included the determination of the shape and morphology of the particles, particle size distribution of powders, the apparent density, and the flow rate of the powders. The shape and morphology of the particles were determined using SEM "Tescan VEGA 3LMU" microscope. The average particle size and particle size distribution of each powder were obtained based on SEM microphotographs, using the image analysis software ImageJ. The particle size was measured along the longest axis. The apparent density and the flow rate of the powders were examined using the Hall flowmeter funnel. The apparent density was done according to the ISO 3923 standard, and the flow rate was according to the ISO 4490 standard [8,9].

The powders were further compacted on a hydraulic press "Mohr & Federhaff & Losenhausen" with a pressure of 600 MPa. The compacts were sintered in a furnace "Elektron ELP-08" in an atmosphere of argon at a temperature of 1000 $^{\circ}\text{C}$ for 2 h, to obtain sintered parts. Density, hardness, and electrical conductivity were measured and the microstructure was analyzed using optical microscopy. The hardness was measured using "VEB Leipzig" Vickers hardness tester with a load of 10 kg. The device "Institute dr. Forster Sigmatest 2.063" was used for measuring electrical conductivity. The optical microscope used to observe the microstructures was "Carl Zeiss Jena Epytip 2".

3. RESULTS AND DISCUSSION

3.1 Characterization of powders

Figure 1 presents SEM microphotographs of copper powders with different sizes and shapes depending on the obtaining method. The water-atomized powders (Figs. 1a-c) appear in an irregular shape while the electrolytic powders show a typical dendritic shape (Figs. 1d-f).

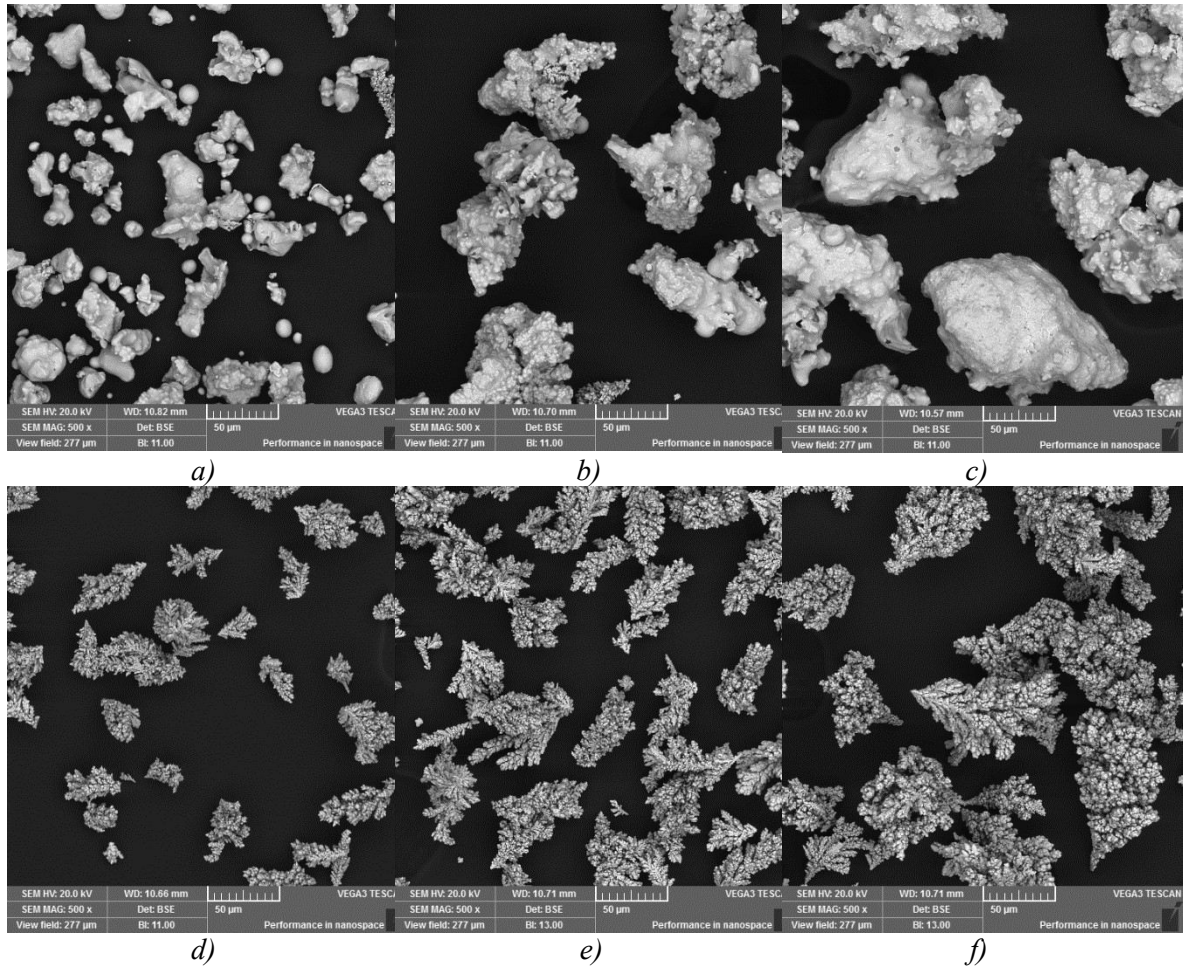
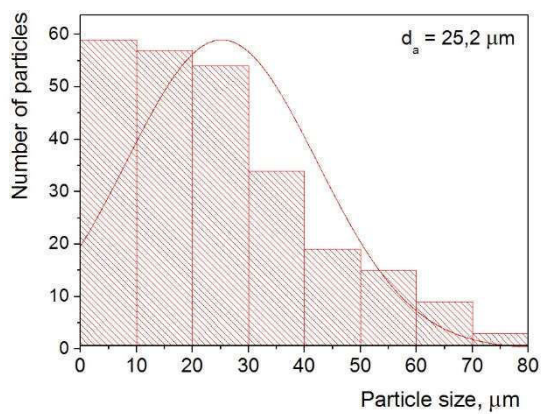
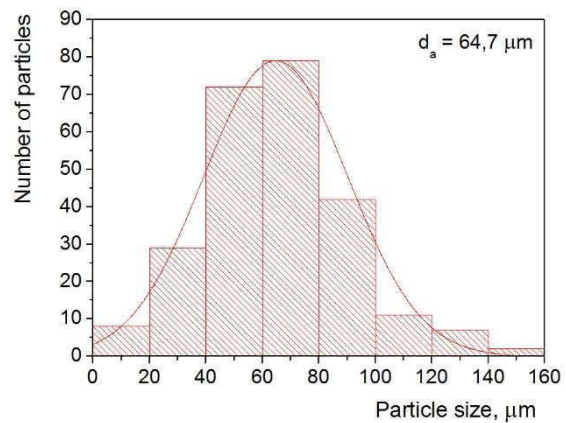


Figure 1. SEM microphotographs of copper powders (a) A-VF; (b) A-F; (c) A-M; (d) E-VF; (e) E-F; (f) E-M

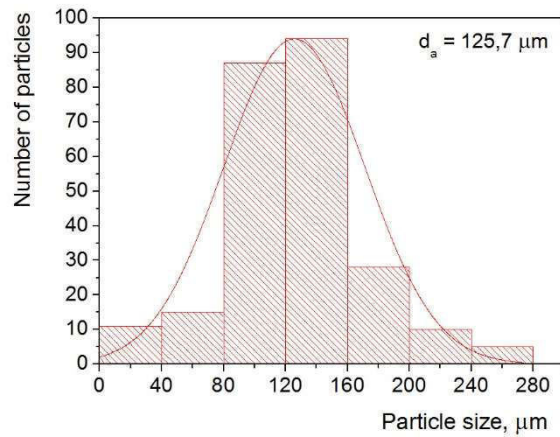
Figure 2 shows the average particle size and particle size distribution of atomized copper powders A-VF, A-F, and A-M. The A-VF powder has the finest average particle size as compared to others, which is 25.2 μm . Powder A-F is coarser, with an average particle size of 64.7 μm . The powder A-M is the coarsest with an average particle size of 125.7 μm .



a)



b)



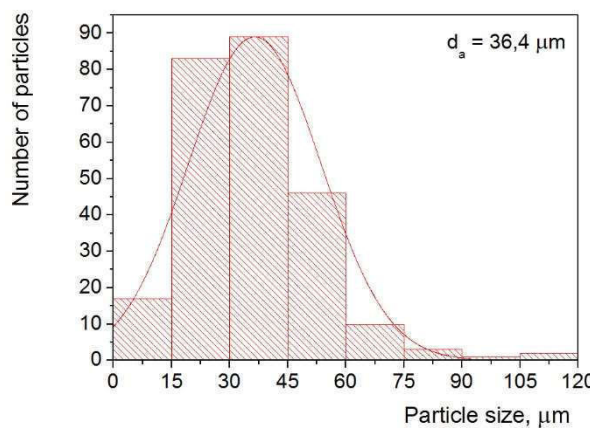
c)

Figure 2. The average particle size (d_a) and particle size distribution of atomized copper powders (a) A-VF; (b) A-F; (c) A-M

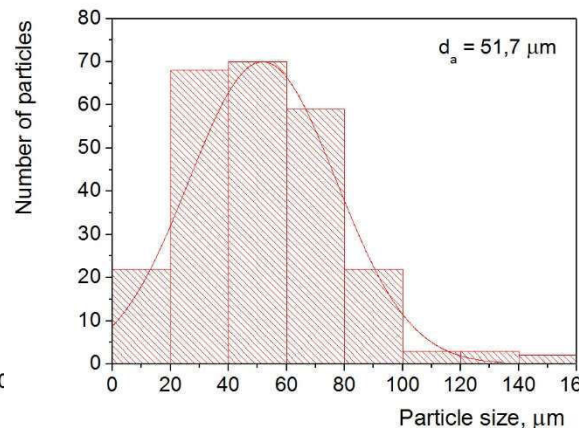
Figure 3 shows the average particle size and particle size distribution of electrolytic copper powders E-VF, E-F, and E-M. The E-VF powder has the finest average particle size, which is 36.4 μm . Powder E-F is coarser, with an average particle size of 51.7 μm . The coarsest electrolytic copper is E-M powder with an average particle size of 84.2 μm .

Comparing the same fractions of atomized and electrolytic powder, it can be noticed that VF atomized powder is finer than electrolytic one, while F and M atomized powders are coarser than F and M electrolytic copper powders, respectively.

Figure 4 shows the apparent density and the flow rate of loose powders. The apparent density of the metal powder is influenced by the theoretical density of the metal, the granulometric composition of the powder, particle shape, surface and roughness of the individual particles, particle packing, oxidation degree, and porosity. Generally, the apparent density increases with an increase in particle size (this behavior was not shown in this paper, but vice versa), if the particle shape becomes less spherical and more irregular and with an increase in surface roughness [10].



a)



b)

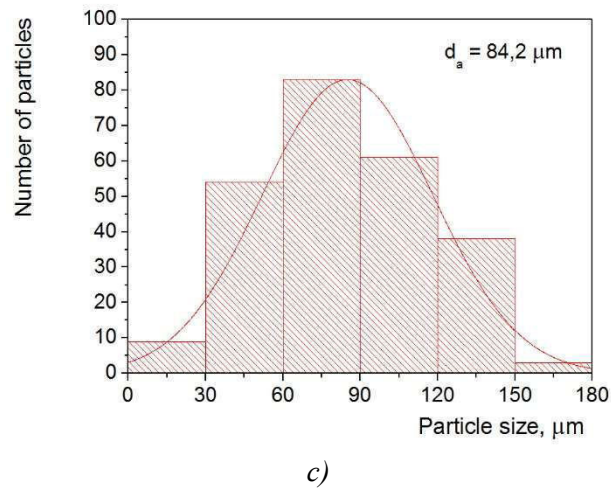


Figure 3. The average particle size (d_a) and particle size distribution of electrolytic copper powders (a) E-VF; (b) E-F; (c) E-M

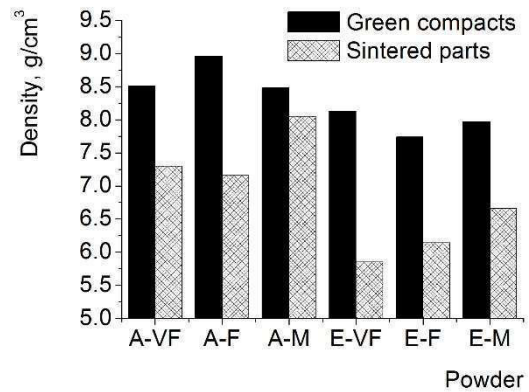
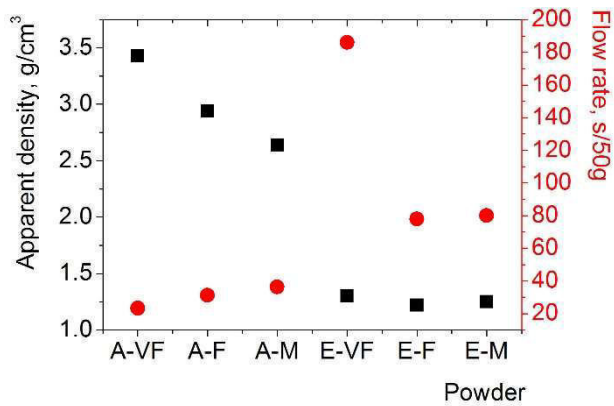


Figure 4. The apparent density and the flow rate of loose powders

Figure 5. The densities of green compacts and sintered parts

It is generally observed that atomized copper powders have higher apparent densities and flow rates compared to electrolytic powders. This is related to the shape of the particles. In the case of dendritic electrolytic copper powder, the presence of bulges and dents in the particle surface, as well as the increase in the specific surface area of the particles increase the friction between particles, this makes it difficult to move the particles relative to each other and causes poor packing of the dendrite particles. Because of that, atomized powders have a higher apparent density and flow rate than dendritic powders [11,12].

The highest apparent density and flow rate are observed for A-VF powder (3.43 g/cm^3 and 23.32 s/50g , respectively). The lowest apparent density was achieved in E-F powder (only 1.22 g/cm^3), while E-VF powder showed the lowest flow rate (186 s/50g).

3.2 Characterization of sintered parts

Figure 5 shows the results of measuring the densities of green compacts and sintered parts from different types of powders. It can be concluded that the density of sintered parts decreased compared to the density of green compacts. This is unusual behavior. The expansion of the parts most likely occurred due to the reaction of residual gases in compacts with the atmosphere in the sintering furnace, i.e. with residual oxygen inside the furnace.

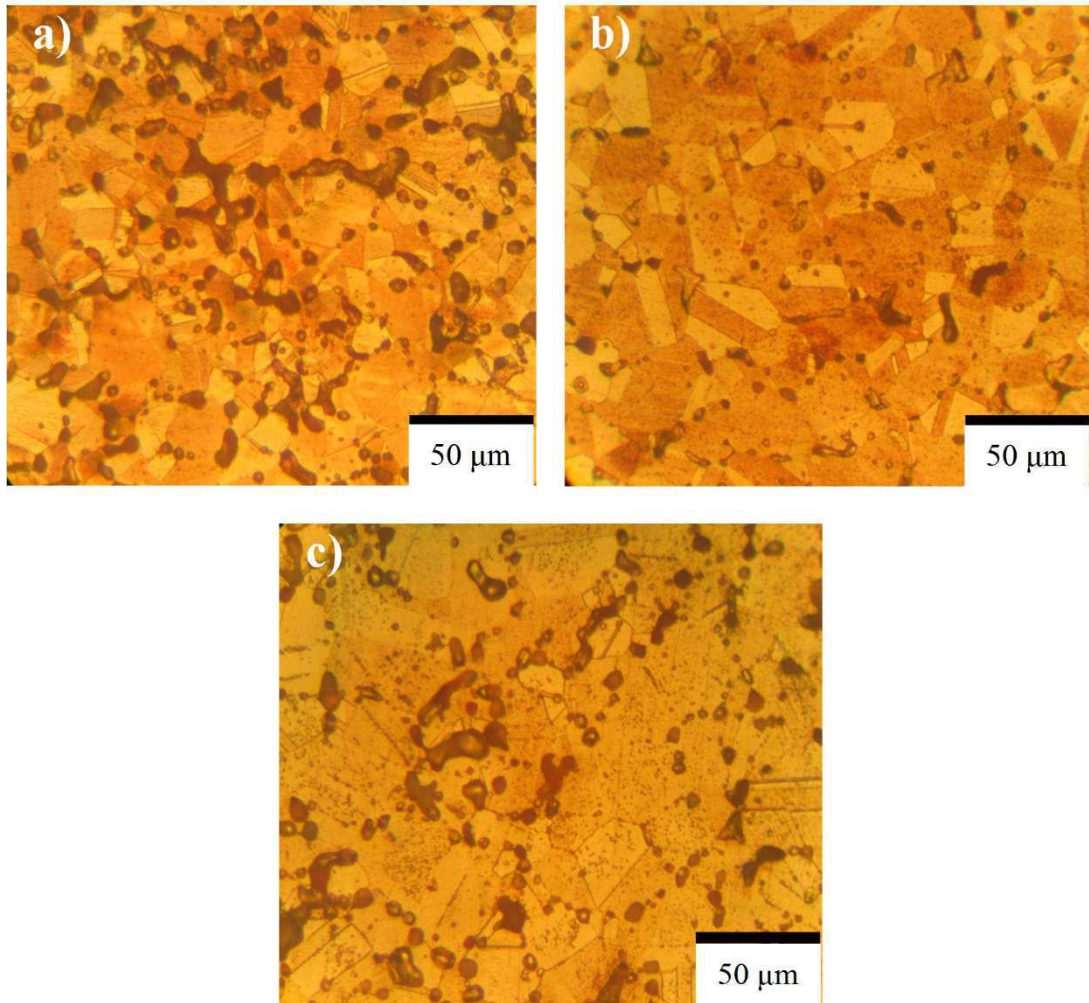


Figure 6. Optical micrographs of sintered copper obtained from atomized powder (a) A-VF; (b) A-F; (c) A-M

Sintered parts obtained from atomized copper powders have significantly higher density values compared to parts obtained from electrolytic copper powders. In the case of parts obtained from electrolytic copper powder, a clear tendency is observed that the density of the parts increases with an increase in the particle size of the starting powder. The same results were obtained by Chang and Wu [4]. This tendency is not expressed in parts obtained from atomized copper powder.

Figure 6 shows the microstructures of sintered parts obtained from atomized powders with different particle sizes. Polygonal grains with annealing twins are observed. The tendency of grains and microstructure consolidation is observed with an increase in the particle size of the starting powder from which the parts were obtained. Spherical pores are present at the grain boundaries and within the crystal grains themselves. The porosity is indicated, especially for the samples obtained from powders A-VF and A-M.

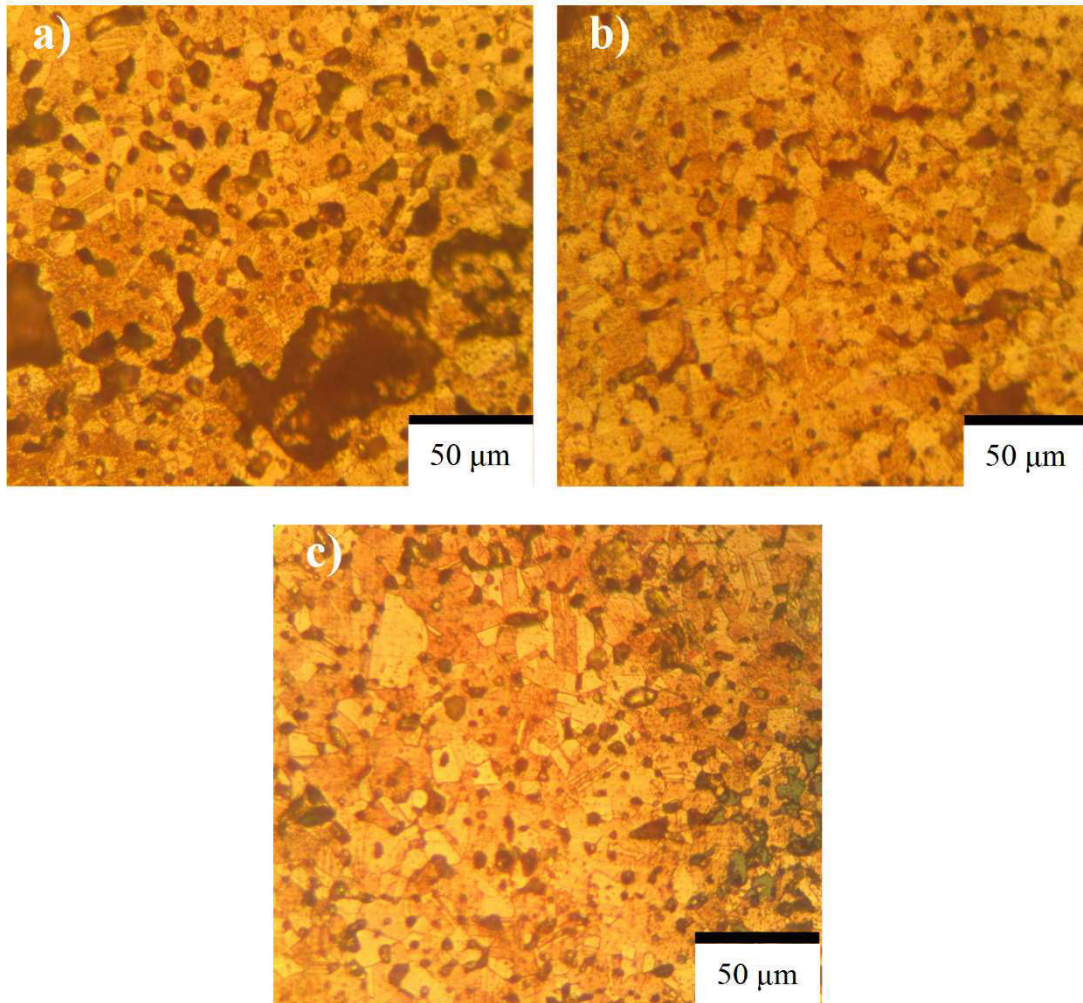


Figure 7. Optical micrographs of sintered copper obtained from electrolytic powder (a) A-VF; (b) A-F; (c) A-M

Figure 7 presents the microstructures of sintered samples obtained from electrolytic powders with different particle sizes. For the same starting powders (the same fractions), a finer-grained microstructure was observed in parts obtained from electrolytic powders compared to parts obtained from atomized powders. The microstructure is dominated by pores, which are large and different in shape. All sintered parts are more porous compared to samples obtained from atomized copper powders. The porosity is the most pronounced for the sample obtained from the electrolytic E-VF powder with the finest particle size, which was also confirmed by the results of the density measurement.

Figure 8 shows the hardness and electrical conductivity of sintered parts obtained from powders of different sizes and shapes. Sintered parts obtained from atomized powders have higher hardness and electrical conductivity values compared to parts obtained from electrolytic copper powders. This is understandable, considering the higher density values of the parts obtained from atomized copper. The sample from A-M powder has the highest hardness value, which is 34.57 HV10. The sample from A-F powder has the highest electrical conductivity, which is 38.15 MS/m. The lowest values of hardness and electrical conductivity were obtained for the parts obtained from the electrolytic copper powder E-VF with the finest particles, which also showed the lowest density value.

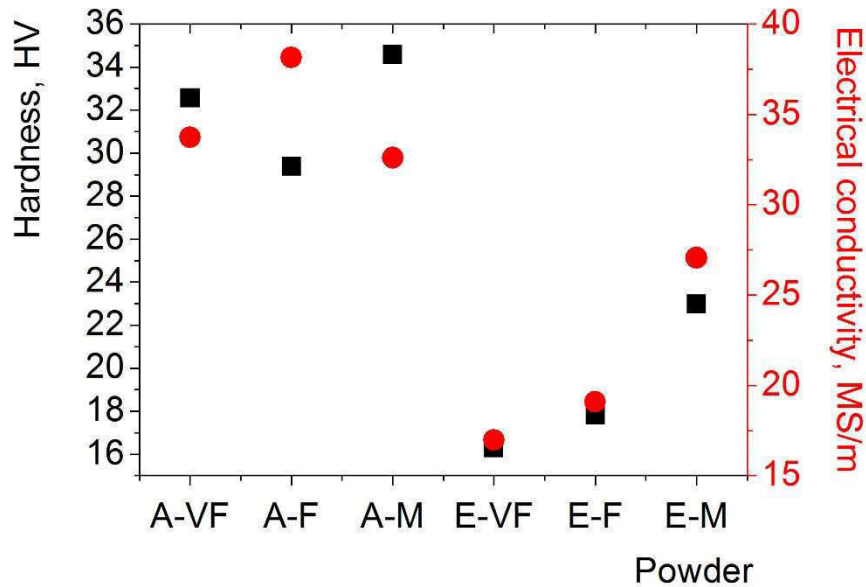


Figure 8. Hardness and electrical conductivity values of the sintered parts

4. CONCLUSIONS

The influence of the copper particle shape and size on some properties of powders, compacts, and PM parts was analyzed. The following conclusions can be drawn:

- Atomized powders showed higher values of apparent density and flow rate compared to electrolytic powders. Increasing the particle size of atomized powder showed a decrease in apparent density and flow rate (atypical behavior). However, increasing the particle size of electrolytic powder showed an increase in flow rate (typical behavior).
- The density of the sintered parts decreased compared to the density of the compacts. Sintered parts obtained from atomized powders have significantly higher density values compared to parts obtained from electrolytic powders.
- The finer microstructure was achieved in sintered parts obtained from electrolytic powders but with much more pronounced pores compared to the parts obtained from atomized powders.
- Sintered parts obtained from atomized powders have higher hardness and electrical conductivity values compared to parts obtained from electrolytic powders.

5. ACKNOWLEDGEMENT

The research presented in this paper was done with the financial support of the Ministry of Science, Technological Development and Innovations of the Republic of Serbia, with the funding of the scientific research work at the University of Belgrade, Technical Faculty in Bor, according to the contract with registration number 451-03-47/2023-01/200131.

6. REFERENCES

- [1] Neikov O.D., Naboychenko S.S.: Handbook of Non-Ferrous Metal Powders: Technologies and Applications, Elsevier, Amsterdam, 2009
- [2] Delavari M., Salarvand A., Rahi A., Shahri F.: The Effect of Powder Metallurgy Process Parameters on Mechanical Properties of Micro and Nano-Iron Powder, International Journal of Engineering, Science and Technology, 3(9) (2011) 86-94
- [3] Kumar N., Bharti A., Dixit M., Nigam A.: Effect of Powder Metallurgy Process and its Parameters on the Mechanical and Electrical Properties of Copper-Based Materials: Literature Review, Powder Metallurgy and Metal Ceramics, 59(2020) 401-410

- [4] Chang C.C., Wu M.R.: Effects of Particle Shape and Temperature on Compaction of Copper Powder at Micro Scale, MATEC Web of Conferences, 123 (2017) 00011
- [5] Edosa O.O., Tekweme F.K., Gupta K.: A Review on the Influence of Process Parameters on Powder Metallurgy Parts, Engineering and Applied Science Research, 49(3) (2022) 433-443
- [6] Sanchez F., Bolarin A.M., Molera P., Mendoza J.E., Ocampo M.: Relationship Between Particle Size and Manufacturing Processing and Sintered Characteristics of Iron Powders, Revista Latinoamericana de Metalurgia y Materiales, 23 (1) (2003) 6
- [7] Vlachos N., Chang I.T.H.: Investigation of Flow Properties of Metal Powders from Narrow Particle Size Distribution to Polydisperse Mixtures Through an Improved Hall-Flowmeter, Powder Technology, 205 (2011) 71-80.,
- [8] Standard ISO 3923-1:2008, Metallic Powders - Determination of Apparent Density - Part 1: Funnel Method, 2008
- [9] Standard ISO 4490:2018, Metallic Powders - Determination of Flow Rate by Means of a Calibrated Funnel (Hall Flowmeter), 2018
- [10] Yadroitsev I.: Selective Laser Melting: Direct Manufacturing of 3D-Objects by Selective Laser Melting of Metal Powders, Central University of Technology, 2009
- [11] Thummler F., Oberacker R.: An Introduction to Powder Metallurgy, The Institute of Materials, London, 1993
- [12] Uslan I., Usta Y., Saritas S.: The Effects of Powder Morphology on the Apparent Density and the Flow Rate of Metal Powders, Powder Metallurgy World Congress, 2006, PD01-W-03