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Inovativni pristop k izboljšanju disperzije kovinskega oksida in strukturno odvisnih lastnosti električnih kontaktnih materialov iz srebrovega/kovinskega oksida brez Cd

Innovative Approach on Improvement of Metal Oxide Dispersion and Structure Dependent Properties of Cd Free Silver/Metal Oxide Electrical Contact Materials

Izvleček

V tem prispevku je opisan poskus inovativnega pristopa za izboljšanje disperzija kovinskih oksidov (MeO) v električnih kontaktnih materialih iz Ag-MeO z vnosom nanodelcev kovinskih oksidov (SnO_2 , ZnO, In_2O_3 , Bi_2O_3 in WO_3) v srebrovo osnovo in pripravo nanokompozitnih prahov z metodo šablone iz topnega škroba. Morfologijo in mikrostrukturo pripravljenih sestavljenih prahov Ag-MeO smo analizirali s SEM in FESEM. Dobljeni rezultati kažejo, da imajo izdelani sestavljeni prahovi veliko stopnjo in enakomernost disperzije nanodelcev kovinskega oksida. Poleg tega smo ugotovili, da so zelo primerni za izdelavo električnih kontaktnih materialov na osnovi Ag-MeO in da so njihove prednosti v izboljšanju homogenosti mikrostrukture ter izboljšanju strukturno odvisnih lastnosti. Pripravljeni in preiskani kontaktni materiali iz Ag- SnO_2 in Ag-ZnO kažejo fino disperzijo oksidov, večjo trdoto in gostoto ter manjšo poroznost in rahlo manjšo električno prevodnost kot ustrezni standardno pripravljene materiali vendar še vedno v zahtevanem območju za trgovske kontaktne materiale te vrste.

Ključne besede: električni kontakti brez Cd, metoda s šablono, Ag-MeO sestavljeni prahovi, morfologija, mikrostruktura, fizikalne lastnosti

Abstract

In the present study an innovative attempt has been made to improve dispersion of metal oxides (MeO) in Ag-MeO electrical contact materials by introducing metal oxide nanoparticles (SnO_2 , ZnO, In_2O_3 , Bi_2O_3 , and WO_3), into silver matrix and preparation of nanocomposite powders by template method using soluble starch as template material. The morphology and microstructure of the prepared Ag-MeO composite powders were studied using SEM and FESEM. The obtained results show that the prepared composite powders exhibit high degree of dispersion of metal oxide nanoparticles and high uniformity. Furthermore, it was found that they are very suitable for further production of Ag-MeO electrical contact materials and that the benefits are primarily illustrated as an improvement of homogeneity of microstructure and structure dependent properties. The prepared and

studied final Ag-SnO₂ and Ag-ZnO contact materials exhibit finer dispersion of oxides, higher hardness, higher density, lower porosity and slightly lower electrical conductivity compared to corresponding conventionally prepared materials, however still within the required range for commercial contact material of this type.

Keywords: Cd free electrical contacts, template method, Ag-MeO composite powders, morphology, microstructure, physical properties

1 Uvod

Električni kontakti na osnovi srebra predstavljajo pomembno in široko uporabljano skupino funkcionalnih materialov [1]. Ker strožja okoljska zakonodaja EU za materiale, ki vsebujejo Cd (RoHS, WEEE), omejuje uporabo splošno zelo dobrih kontaktov iz Ag-CdO, se vlagajo veliki naporji v razvoj alternativnih električnih kontaktov brez Cd. Čeprav so se materiali iz Ag-SnO₂ in Ag-ZnO zdeli kot zelo obetavna, okolju bolj prijazna zamenjava, se pri povišanih temperaturah sorazmerno slabo obnašajo in imajo slabo preoblikovalnost, če so izdelani po klasičnih postopkih. Dosedanje raziskovalne izkušnje kažejo, da je najpomembnejši parameter za doseganje homogene mikrostrukture zelo fina disperzija kovinskega oksida v srebrovi osnovi in da je splošno sprejeto dejstvo, da se delovanje kontaktnih materialov iz Ag-MeO lahko občutno izboljša z boljšo disperzijo sestavljenih prahov, kar se navadno doseže z uporabo ali sintezo drobnejših delcev kovinskega oksida [2]. Drobnejše mikrostrukture so boljše, še posebej, kadar se uporabljajo različni kovinski oksidi, ki spreminjajo lastnosti materialov s spreminjanjem interakcije med srebrovo osnovo in glavnim kovinskim oksidom [2,3,4]. Poleg tega je sprejeto dejstvo, da drobnejši kovinski oksidni delci izboljšujejo odpornost protizvarjanju kontaktov in v določenih razmerah zmanjšujejo stopno erozije [5]. Če upoštevamo, da je disperzija oksida neposredno povezana

1 Introduction

Silver based electrical contacts represent a significant and widely used group of functional materials [1]. As stricter EU environmental legislations concerning materials containing Cd (RoHS, WEEE) limit the use of generally superior Ag-CdO contacts, significant efforts are undertaken to develop alternative Cd-free electrical contacts. Although, Ag-SnO₂ and Ag-ZnO have emerged as promising, more environmentally friendly replacements, when they are produced by common processing routes they are characterized by rather poor over-temperature behavior and poor workability. So far research experience shows that the most important factor for obtaining homogenous microstructure is very fine metal oxide dispersion in silver matrix and as it is generally accepted that the performance of Ag-MeO contact materials can be enhanced by increase in the composites dispersion, which is usually achieved by use or synthesis of finer metal oxide particles [2]. Finer microstructures are advantageous especially when different metal oxides are used that alter the materials properties by changing the interaction between silver matrix and the main metal oxide [2,3,4]. Furthermore, it is accepted that smaller metal oxide particles promote anti-welding characteristics and under certain conditions decrease erosion rate [5]. Considering that the oxide dispersion is directly related to an applied processing technique, a variety of production routes has

z uporabljenim načinom izdelave, je bilo razvitih več teh načinov. Vendar dosežejo standardne mokre ali suhe metode mešanja prahov svoje tehnične meje pri velikosti delcev 1–2 mikrometra zaradi bolj ali manj izrazitega skepljanja [6]. Poleg tega je izboljšana disperzija kovinskega oksida in s tem homogenost mikrostrukture kontaktnih materialov iz Ag-MeO možna le z alternativnimi pristopi priprave začetnih sestavljenih prahov. Zato so raziskovalci preiskali različne negalvanske kemične metode izločanja delcev. Dodatno moderne metode s polimeri podprte tvorbe anorganskih nanokompozitov in metod bioulivanja, ki uporabljajo različne organske šablone, nudijo nove možnosti za pripravo zelo enakomernih nanokompozitnih delcev [5-8].

Glede na povedano smo v tem prispevku opisali inovativni poskus, kako povečati disperzijo Ag-MeO v kontaktnih materialih z uvajanjem kovinskih oksidnih nanodelcev v srebrno osnovo in pripravo nanokompozitnih prahov z metodo škrobne šablone. Prikazali bomo vpliv uporabe kovinskih oksidnih nanodelcev in njihovega uvajanja v srebrno osnovo na izboljšanje disperzije in enakomernosti mikrostrukture pripravljenih sestavljenih prahov ter o tem razpravljali. Poleg tega bomo prikazali mikrostrukturno odvisne lastnosti, kot so gostota, poroznost, trdota in električna prevodnost, na primerih izdelanih kontaktnih materialov na osnovi Ag-SnO₂ in Ag-ZnO in primerjali med seboj te materiale s standardno izdelanimi materiali iste vrste.

2 Eksperimentalni del

Prahove, sestavljene iz srebra in kovinskega oksida, smo izdelali po prilagojeni metodi s šablono [9]. Uporabili smo trgovske nanodelce oksidov SnO₂, ZnO, In₂O₃, Bi₂O₃,

been developed. However, conventional powder mixing methods either wet or dry, reach their technical limit at powder particle sizes of about 1-2 microns due to more or less pronounced agglomerate formation [6]. Further improvement of metal oxide dispersion and thus homogeneity of microstructure of Ag-MeO contact materials is only possible by using alternative approaches in preparation of starting powder composites. For that purpose different electroless chemical methods based on chemical precipitation were investigated. In addition, modern polymer assisted inorganic nanocomposite formation and bio-casting methods that utilize different organic templates offer new possibilities for preparation of very uniform nanocomposite structures [5-8].

In view of that, in the current study an innovative attempt has been made to increase dispersion of Ag-MeO contact materials by introducing metal oxides nanoparticles in silver matrix and preparation of nanocomposite powders by template method using soluble starch as a template material. The effect of using metal oxide nanoparticles and method of their introduction in silver matrix on improvement of dispersion and uniformity of microstructure of the prepared composite powders were studied and discussed. In addition, structure dependent properties such as: density, porosity, hardness and electrical conductivity are demonstrated on the examples of the produced final Ag-SnO₂ and Ag-ZnO contact materials and compared to each other and to conventionally prepared materials of the same type.

2 Experimental

Silver-metal oxide composite powders were produced by a modified template

in WO_3 , velikosti 40–100 nm ter trgovski prah AgNO_3 kot prekursorje. Uporabljena metoda sinteze uporablja škrob kot mehko organsko šablono in sloni na preprosti predpostavki, da se AgNO_3 za razliko od večine kovinskih nitratov pri segrevanju razkroji na elementno srebro namesto na ustrezen oksid. V prvi fazi smo dodali v destilirano vodo topni škrob in ga ob stalnem mešanju segreli na 40–50 °C. Raztopino smo potem segreli na temperaturo vrelišča (~100 °C) in jo pri tej temperaturi držali 15 min, potem pa smo jo ohladili na 50–70 °C. Predhodno pripravljeno suspenzijo nanodelcev kovinskega oksida smo počasi dodajali. AgNO_3 , delci kovinskega oksida pa so bili dodani v količini, potrebni, da se doseže željeno masno razmerje Ag:kovinski oksid v končnem materialu, tj. Ag-SnO₂ (92:8); Ag-ZnO (92:8); Ag-SnO₂In₂O₃ (89,1:8:2,9); Ag-SnO₂WO₃ (90:9,5:0,5) in Ag-SnO₂In₂O₃Bi₂O₃ (89,2:8,7:0,5:1,6). Pripravljene mešanice smo sušili v sušilni komori pri 80 °C, dokler ni voda izparela in so ostali trdni sestavljeni prahovi. Te prahove smo potem segreli in žarili v mufelni peči 4 ure pri 650 °C. Pri tem je srebrov nitrat razpadel v elementno srebro, ki se je nahajalo med nanodelci kovinskega oksida. Škrobovo šablono smo nato odstranili. Vzorci končnih kontaktnih materialov Ag-SnO₂ in Ag-ZnO so bili izdelani iz dobljenih sestavljenih prahov po standardni metodi metalurgije prahov. Razmere pri izdelavi so podrobno opisane v [10]. Morfologijo in mikrostrukturo izdelanih sestavljenih prahov smo analizirali z vrstičnim elektronskim mikroskopom (SEM) JEOL JSM 6610LV in vrstičnim elektronskim mikroskopom s poljsko emisijo (FESEM) Tescan MIRA3. Gostoto vzorcev končnih električnih kontaktnih materialov smo ugotavljali s standardnimi metodami. Trdoto smo merili na poliranih vzorcih pri sobni temperaturi z merilnikom trdote po Vickersu z obtežbo 5 kp. Podane trdote predstavljajo

method [9] using commercial SnO₂, ZnO In₂O₃, Bi₂O₃, and WO₃ nanoparticles (40–100 nm) and commercial AgNO₃ powder as precursors. The applied synthesis method utilizes starch as a soft organic template and it is based on a simple principle that AgNO₃, unlike most metal nitrates, when heated thermally decomposes to elemental Ag instead of its respective oxide. In the first step soluble starch was added into distilled water, preheated at 40–50 °C under continuous stirring. Solution was further heated up to boiling point (~100 °C), where it was kept for 15 min, and then cooled down to 50–70 °C. Previously prepared metal oxide nanoparticle suspensions were slowly added to solution during vigorous mixing. After few minutes AgNO₃ water solution was slowly added. Both AgNO₃ and metal oxide particles were added in quantities necessary to achieve desired Ag to metal oxide weight ratio in final material i.e. Ag-SnO₂ (92:8); Ag-ZnO (92:8); Ag-SnO₂In₂O₃ (89.1:8:2.9); Ag-SnO₂WO₃ (90:9.5:0.5) and Ag-SnO₂In₂O₃Bi₂O₃ (89.2:8.7:0.5:1.6). The prepared mixtures were dried at 80 °C in chamber dryer until water was evaporated and solid composites were obtained. The solid composites were subsequently burned and put into a muffle furnace pre-heated at 650 °C, where they were calcinated for 4h. During the combustion and later calcination, silver nitrate was transformed to elemental Ag with embedded metal oxide nanoparticles and the starch template was removed. Samples of final Ag-SnO₂ and Ag-ZnO contact materials were prepared from the obtained composite powders via conventional powder metallurgy route. The processing conditions are given in more detail in [10]. Morphology and microstructure of the prepared composite powders were studied using JEOL JSM 6610LV scanning electron microscope (SEM) and Tescan MIRA3 XM field emission scanning electron

povprečje 5 meritev. Električno prevodnost preiskanih materialov smo merili na vzorcu s premerom 8 mm z merilnikom na vrtnične tokove Foerster SIGMATEST 2.069.

3 Rezultati in razprava

Morfologijo sestavljenega prahu srebrokositrov oksid, izdelanega po metodi s škrobovo šablono, prikazujejo SEM-mikrosposnetki na sliki 1.

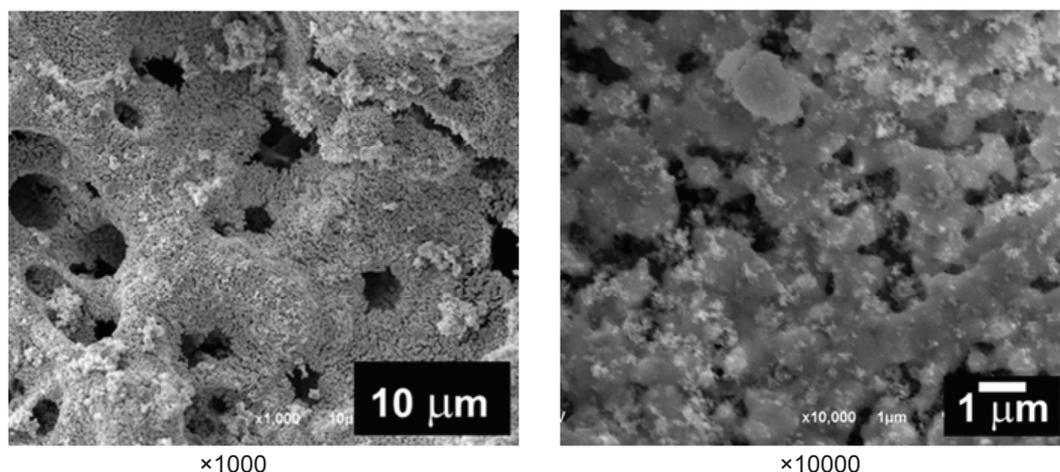
Dobljene sestavljene zgradbe spominjajo na intersticijski prostor v strjeni škrobovi osnovi, ki ga je prvotno zasedala mešanica prekurzorjev, a bi se lahko nanašal tudi na sprostitvev plinov med odstranjevanjem šablone. Očitno smo dosegli zelo dobro mešanje in veliko disperzijo nanodelcev v srebrovi osnovi. Če vzamemo, da proces ni preveč dolgotrajen, da odstranjevanje škroba ni preveč zapleteno in da ni ovir za istočasno uvajanje različnih kovinskih oksidov, smo ta material za šablono izbrali pri nadaljnji izdelavi sestavljenih prahov.

microscope (FESEM). Density of the samples of final electrical contact materials was determined by standard methods. Hardness measurements were carried out on polished samples at room temperature using a Vickers hardness tester applying load of 5 kp. The reported hardness values are an average of five readings. Electrical conductivity of the investigated materials was measured using Foerster SIGMATEST 2.069 eddy current instrument with an 8 mm diameter probe.

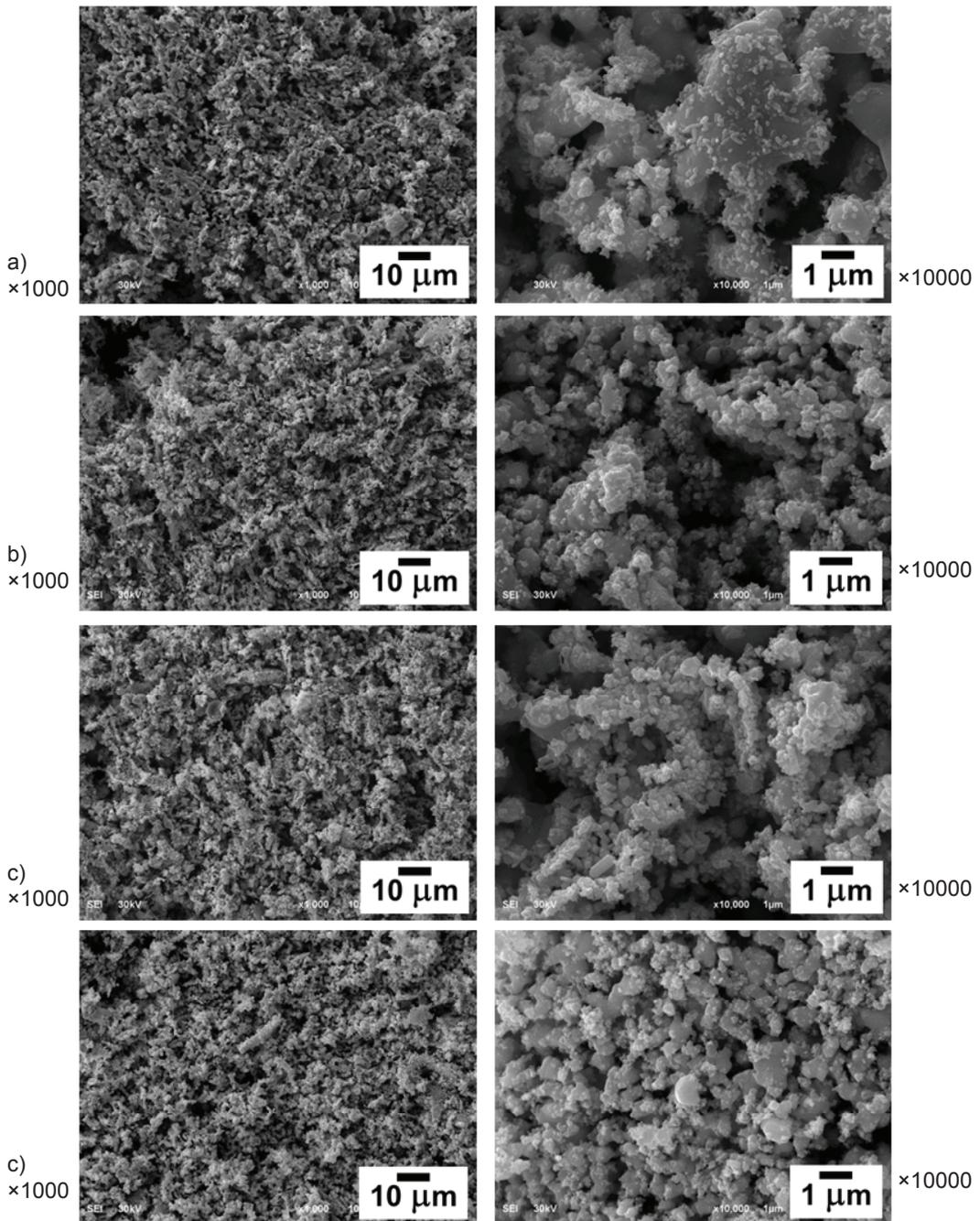
3 Results and discussion

Morphology of the silver tin-oxide composite powder prepared by template method using starch as a template material is illustrated by SEM images presented on Fig 1.

The obtained composite structure resembles the interstitial space within the solid starch matrix that was initially occupied by the precursor mixture but it can also be related to the release of gases during the template removal stage. It is evident that



Slika 1. Morfologija sestavljenega prahu Ag-SnO_2 , izdelana po metodi z uporabo šablone
Fig.1. Morphology of the Ag-SnO_2 composite powder prepared using template method



Slika 2. Morfologija sestavljenih prahov Ag-MeO, izdelanih po šablonski metodi:

a) Ag-ZnO, b) Ag-SnO₂In₂O₃, c) Ag-SnO₂WO₃, d) Ag-SnO₂In₂O₃Bi₂O₃

Figure 2. Morphology of the Ag-MeO composite powders prepared using template method:

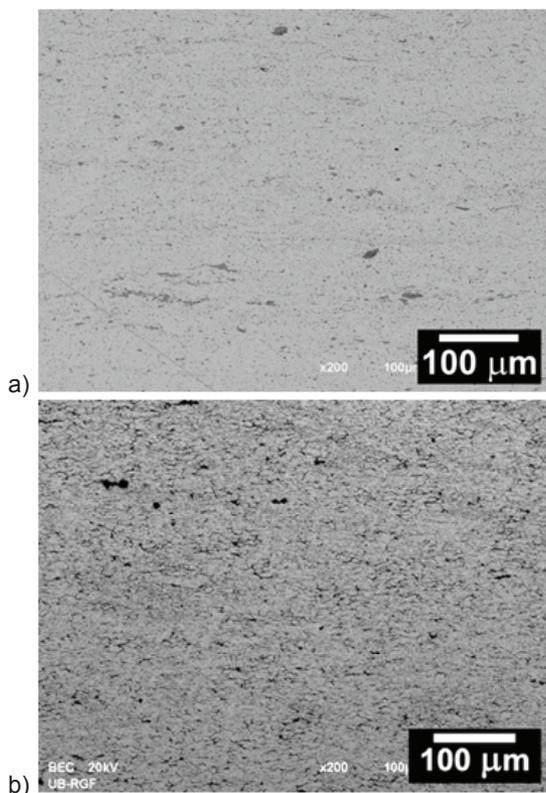
a) Ag-ZnO, b) Ag-SnO₂In₂O₃, c) Ag-SnO₂WO₃, d) Ag-SnO₂In₂O₃Bi₂O₃

SEM posnetki na sliki 2 kažejo morfologijo izdelanih in preiskanih sestavljenih prahov Ag-MeO. Tako smo prikazali in potrdili prednosti uporabljene metode s šablono: dobro mešanje, veliko disperzijo nanodelcev kovinskega oksida in veliko enakomernost. Rezultati SEM-analize kažejo, da je metoda s šablono zelo primerna za istočasno uvajanje nanodelcev več kovinskih oksidov v srebrno osnovo. To je pomembno predvsem zato, ker so pri uporabljenem postopki s šablono oksidni delci inkapsulirani v srebrovi osnovi in se izognemo izcejam. Zato predstavljajo izdelani sestavljeni prahovi zelo primerne prekursorje za izdelavo električnih kontaktnih materialov.

a very good mixing and high dispersion of nanoparticles in silver matrix were obtained. Given that the process is not too time demanding and that removal of starch is not too complicated, and that there are no obstacles to introduction of different metal oxide nanoparticle at the same time, this template material was adopted for further preparation of composite powders.

The SEM images presented on Fig. 2 illustrate morphology of the prepared and investigated Ag-MeO composite powders and demonstrate and confirm the advantages of the applied template method such as: good mixing, high dispersion of metal oxide nanoparticles and high uniformity. The results of SEM analysis show that the template method is very suitable for simultaneous introduction of multiple metal oxide nanoparticles into silver matrix. This is primarily because in course of the applied template process oxide particles are encapsulated within silver matrix and thus segregation is avoided. Accordingly, the prepared composite powders represent very favorable precursors for the production of electrical contact materials.

In order to illustrate the benefits of using composite powders for production of electrical contacts the samples of Ag-SnO₂ and Ag-ZnO contact materials were prepared by powder metallurgy method and for comparison corresponding microparticle materials were prepared by using conventional mixing and the same powder metallurgy route.

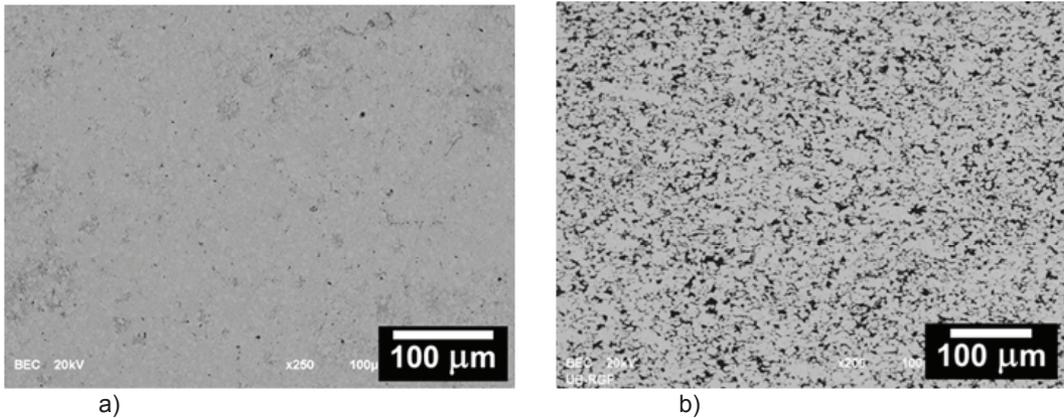


Slika. 3. Mikrostruktura končnega kontaktnega materiala na osnovi Ag-SnO₂ po:

a) metodi s šablono in b) s klasičnim mešanjem

Figure 3. Microstructure of the final Ag-SnO₂ contact material prepared using:

a) template method and b) conventional mixing



Slika 4. Mikrostruktura končnega kontaktnega materiala na osnovi Ag-ZnO, izdelanega po: a) metodi s šablono in b) s klasičnim mešanjem

Figure 4. Microstructure of the final Ag-ZnO contact material prepared using: a) template method and b) conventional mixing

Da bi ponazorili prednosti uporabljenih sestavljenih prahov pri izdelavi električnih kontaktov, smo vzorce kontaktnih materialov iz Ag-SnO₂ in Ag-ZnO izdelali po postopkih metalurgije prahov in jih primerjali z materiali iz nanodelcev, ki so bili izdelani s standardnim mešanjem prahov in nato izdelani po postopkih metalurgije prahov.

Mikrostrukture izdelanih končnih kontaktov na osnovi Ag-SnO₂ in Ag-ZnO po sintranju, strojni obdelavi in dodatnem žarjenju prikazujejo SEM-metalografski posnetki poliranih brusov na slikah 3 in 4.

Prikazane slike materiala na osnovi Ag-SnO₂ (slika 3) kažejo bistvene razlike v enakomernosti dobljenih materialov. Očitno je v vzorcih, izdelanih po šablonski metodi (slika 3a), disperzija oksida občutno večja, medtem ko je mikrostruktura vzorca, izdelanega s klasičnim mešanjem (slika 3b) manj drobna in bolj porozna, pri čemer se delci MeO nahajajo predvsem na mejah srebrih zrn.

Praktično enak rezultat smo dobili pri materialu Ag-ZnO (slika 4). Predpostavili smo, da opažene razlike pri mikrostrukturi najverjetneje vplivajo na strukturno odvisne

Microstructures of the prepared final Ag-SnO₂ and Ag-ZnO contacts after sintering, mechanical treatment and subsequent annealing are illustrated by SEM metallographic images of polished cross-sections presented on Fig. 3 and Fig. 4, respectively.

The presented images of the Ag-SnO₂ material (Fig. 3) demonstrate substantial differences in uniformity of the obtained materials. It is evident that the sample prepared by template method (Fig. 3a) has significantly higher oxide dispersion whereas microstructure of the sample prepared by conventional mixing route (Fig. 3b) appears to be less fine and more porous with MeO particles predominantly situated on silver grain boundaries.

In case of Ag-ZnO material (Fig. 4) practically the same result was obtained. It can be assumed that the observed differences in microstructure will most certainly affect structure dependent properties of the prepared Ag-MeO electrical contacts. For that reason the comparative presentation of the physical properties of the

Razpredelnica 1. Primerjava fizikalnih lastnosti električnih kontaktnih materialov na osnovi Ag-MeO**Table 1.** Comparative overview of physical properties of the prepared Ag-MeO electrical contact materials

Metoda izdelave / Preparation method	Sestava / Composition	Gostota / Density [g/cm ³]	Trdota / Hardness [HV5]	Prevodnost / Conductivity	
				[MS/m]	[%IACS]
Metoda s šablono/ metalurgija prahov / Template method / powder metallurgy	Ag-SnO ₂ (92:8) nano	9,86	123	38,92	67
Klasično mešanje/ metalurgija prahov / Conventional mixing / powder metallurgy	Ag-SnO ₂ (92:8) mikro	9,53	87	44,75	77
Metoda s šablono/ metalurgija prahov / Template method / powder metallurgy	Ag-ZnO (92:8) nano	9,55	96	35,27	61
Klasično mešanje/ metalurgija prahov / Conventional mixing / powder metallurgy	Ag-ZnO (92:8) mikro	9,49	82	38,65	67

lastnosti električnih kontaktov na osnovi Ag-MeO. Zato smo pripravili primerjavo fizikalnih lastnosti izdelanih električnih kontaktnih materialov, kar prikazuje razpredelnica 1.

Rezultati v razpredelnici 1 kažejo, da imajo materiali na osnovi Ag-SnO₂ in Ag-ZnO, izdelani po šablonski metodi, večjo gostoto in trdoto kot klasično izdelani iz mikrodelcev. Na osnovi vidnih mikrostruktur smo privzeli, da smo se z uporabo šablonske metode izognili skepljenju in ločenju oksidnih delcev ter s tem dobili drobnejše in bolj enakomerne mikrostrukture, ki so omogočile večje disperzijsko utrjevanje. Takšne izboljšane lastnosti so želene za uporabo materialov glede na boljšo obrabno trdnost, večjo odpornost proti zvarjenju kontaktov in s tem daljšo življenjsko dobo. Nasprotno pa lahko višje vrednosti električne prevodnosti pripišemo manj enakomernim mikrostrukturam in prisotnosti con brez oksidov, kar omogoča boljše povezanost srebrovih zrn. Nekoliko manjša prevodnost materialov, izdelanih s šablonsko metodo, je bila pričakovana, ker se na splošno električna prevodnost zmanjšuje z manjšanjem oksidnih delcev in povečevanjem njihove disperzije zaradi spremembe srednje proste poti prevodnih

prepared final silver-metal oxide electrical contact materials is given in Table 1.

From the presented results (Table 1) it can be seen that Ag-SnO₂ and Ag-ZnO materials prepared via template method have higher density and hardness compared to conventionally prepared microparticle ones. In line with the observed microstructures, it can be assumed that this is due to the fact that by using template method agglomeration and segregation of oxide particles were avoided finer and more uniform microstructures were obtained that enabled greater dispersion hardening. Such improved properties are desired from the application point of view in terms of better wear resistance, better anti-welding behavior and thus longer exploitation life. In contrast, higher values of electrical conductivity of the microparticle materials can be ascribed to the less uniform microstructures and presence of oxide free zones that provide better connectivity of the silver grains. Somewhat lower conductivity of the materials prepared by template method is expected since electrical conductivity generally decreases with reduction of oxide particle size and increase of their dispersion due to changes

elektronov [5,6,11]. Kljub temu so izmerjene vrednosti električne prevodnosti še v zahtevanih mejah za trgovske električne kontakte te vrste.

4 Sklepi

Preučevali smo inovativni pristop za izboljšanje disperzije kovinskega oksida v materialih za električne kontakte na osnovi srebro/kovinski oksid in o njem razpravljali. Uporabili smo prilagojeno šablonsko metodo s škrobom kot mehko organsko šablono za uvajanje nanodelcev kovinskega oksida v srebrovo osnovo in za izdelavo začetnih sestavljenih prahov Ag-MeO. Ugotovili smo, da imajo izdelani sestavljeni prahovi Ag-MeO veliko stopnjo disperzije oksidnih delcev in zelo enakomerno njihovo porazdelitev. Dodatne prednosti uporabljene sintezne metode je možnost uvajanja različnih kovinskih oksidov tudi istočasno in primernost za uvajanje nanodelcev kovinskega oksida. Dobljeni sestavljeni prahovi Ag-MeO se lahko uspešno uporabijo za izdelavo končnih električnih kontaktnih materialov z izboljšano disperzijo in s tem izboljšanimi mehanskimi lastnostmi, ker se z uporabljenimi šablonsko metodo izognemo skepljenju in razmešanju oksidnih delcev. Primerjava z ustreznimi kontaktnimi materiali, izdelanimi na klasičen način, kaže pri materialih, izdelanih s šablonsko metodo s topnim škrobom, finejšo disperzijo kovinskih oksidov, večjo gostoto, večjo trdoto, manjšo poroznost in rahlo zmanjšano električno prevodnost, vendar pa so lastnosti še vedno primerljive z lastnostmi električnih kontaktnih materialov te vrste, izdelanih iz standardnih trgovskih mikrododelcev.

in mean free path of conduction electrons [5,6,11]. Nevertheless, the measured values of electrical conductivity are still in the required range for commercial electrical contacts of this type.

4 Conclusion

The innovative approach on improvement of metal oxide dispersion in cadmium-free silver/metal oxide electrical contact materials was studied and discussed. The modified template method using starch as a soft organic template was applied for introduction of metal oxide nanoparticles into silver matrix and for preparation of starting Ag-MeO composite powders. It was found that the prepared Ag-MeO composite powders exhibit high degree of dispersion and very uniform distribution of oxide particles. Additional advantages of the applied method of synthesis are possibility of introduction of different metal oxides even at the same time and suitability for introduction of metal oxide nanoparticles. The obtained Ag-MeO composite powders can be successfully used for further production of final electrical contact materials with improved dispersion and hence improved mechanical properties due to the fact that by using template method for preparation of composite powders agglomeration and segregation of oxide particles were avoided. Compared to corresponding contact materials prepared by conventional route, contact materials prepared by template method using soluble starch as a template, exhibit finer dispersion of metal oxides, higher density, higher hardness, lower porosity and slightly reduced electrical conductivity, however still comparable with those of conventional commercial microparticle electrical contact materials of this type.

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