Influence of 3D Surface Roughness Parameters of Powder Iron-Copper Details on the Wear Intensity

Irina Boiko[1], Oskars Lininsh[2], Andris Kamols[3], [1-3]*Riga Technical University, Institute of Mechanical Engineering*
Viktors Mironovs, *Riga Technical University, Scientific Laboratory of Powder Materials*

Abstract **– A brief review of the state and development of Powder Metallurgy is given. The experimental and theoretical results of the influence of the 3D surface roughness parameters of powder iron-copper details on the wear intensity are presented. It is shown that the higher wear intensity is achieved for iron-copper powder details after infiltration, i.e. after the final stage of production. Nevertheless, the achieved results show the possibility of successful use of such details for different applications in industry.**

Keywords **– powder metallurgy, infiltration, 3D surface roughness parameters, wear intensity.**

I. INTRODUCTION

Powder metallurgy has grown with the expansion of various industries since 1950. Nowadays, over 90% PM products are used in the transportation market [1]. Powder Metallurgy is a materials processing technology used to create new materials and parts by diffusing different metal powders as raw ingredients through the sintering process. The fundamental process of PM is shown in Fig.1.

The place of PM in the material process technology industry is shown in Fig.2. It should be mentioned that PM is very economical production with little waste [1].

Currently, the performance friction materials for, for example, automotive braking systems consist of composites made by Powder Metallurgy with metallic matrix from copper, iron or aluminum reinforced with a) friction components (such as oxides: Al_2O_3, SiO_2, ZrO_2, nitrides: TiN, Si_3N_4, carbide: SiC, TiC, B_4C) improving the wear resistance and c) lubrication components (graphite, molybdenum disulfide, etc.), facilitating improvement of material resistance to gripping and wear reduction of disc (rotor) brake [2].

Copper and iron have been used extensively for various tribological applications [1-3]. The copper and iron-based friction materials are most often fabricated using Powder Metallurgy (PM) technique due to its many advantages such as the elimination of solidification induced chemical segregation and structural defects often accompanied by melting and solidification processes. The ease in mixing of different powders leads to the possibility for developing new composite materials with special physical and mechanical properties that are otherwise difficult to manufacture [3].

In some cases, the cost of expensive alloying elements can be avoided and micro-alloying can be applied, in this case the amount of additive usually is from 0.1 to 5%. Some authors assumed that dispersed additives have great potential for microalloying and nanoalloying [1,4,5]. Thus, the introduction of nanopowders of copper or copper-iron ligature into a powder iron-based material has led to an increase in strength, hardness, density, and to reduction in sintering temperature [5].

Good results were achieved by adding nickel and molybdenum, but the costs of such elements have risen sharply in the recent years [1].

Authors of [6] proposed new antifriction materials based on iron-copper powders with several additional elements which cost less, such as tin, lead and molybdenum disulphide (Fe-Cu-Sn-Pb-MoS_2system with 2.5% Sn and 2.5% Pb additions sintered at 900°C for 50 minutes) which have been developed by PM techniques in order to improve antifriction and mechanical properties.

Some researches [1] forecast that PM in the future will be used not only for manufacturing of machine parts and other elements for automotive industry and machinery, but also for producing of micro parts for medical and other precision equipment as well as for manufacturing of microsensors. The trends in compacting technologies and material technologies in PM in the future are shown in Figure 3.

In the recent years iron-based sintered bearings production

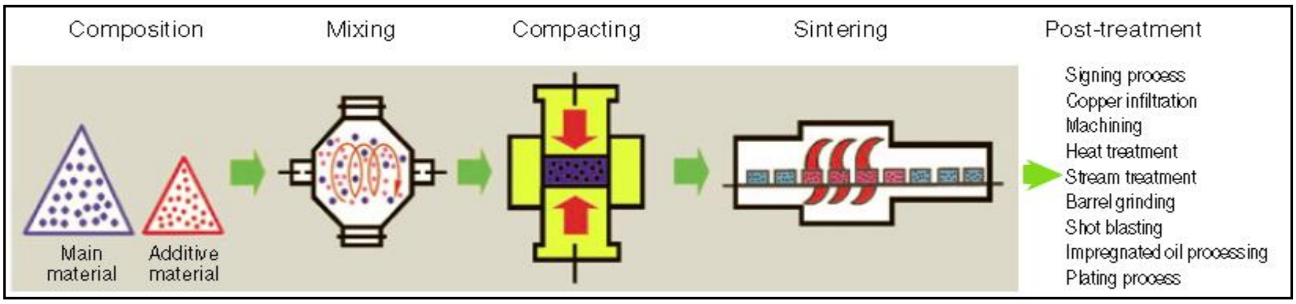


Fig.1. Fundamental process of Powder Metallurgy [1]

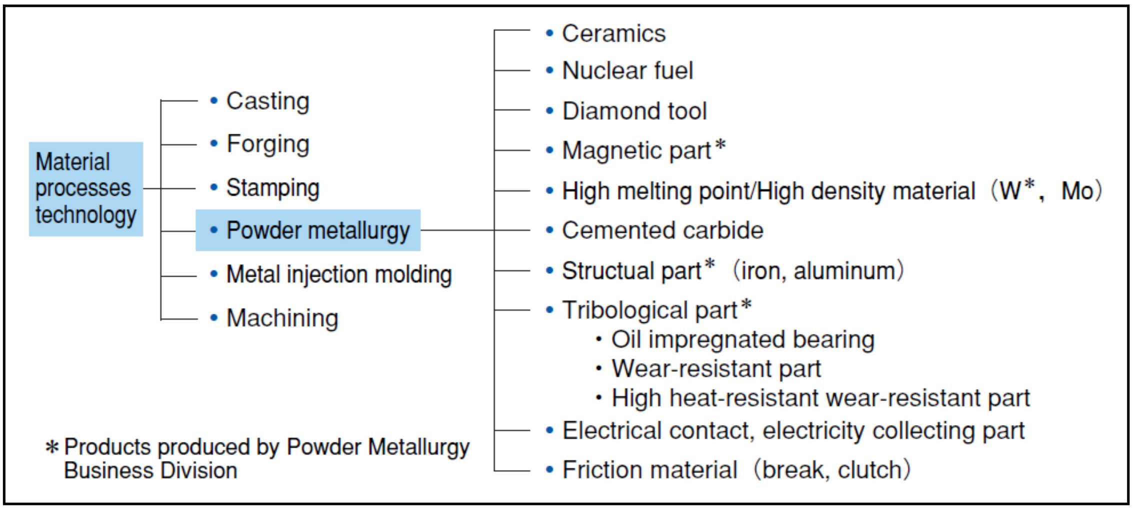


Fig.2. Products produced by PM within the Material Processes Technology [1].

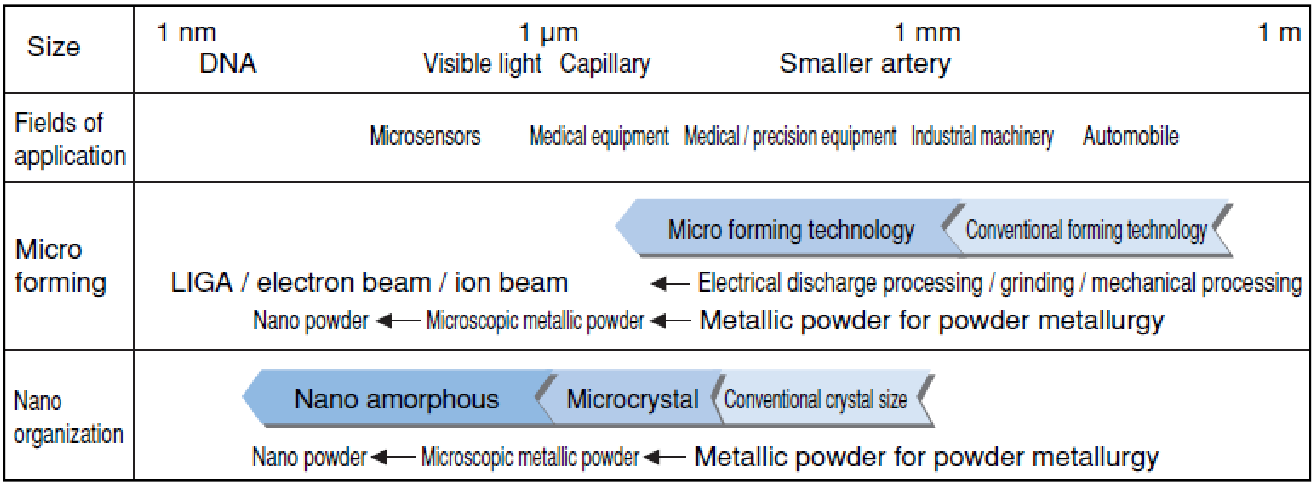


Fig.3. Trends in compacting technologies and material technologies in PM [1].

has considerably increased at the expense of the copper-based ones, due to the low cost and availability of the iron powders as well as their higher strength [7,8]. It should be mentioned here that mixtures of iron and copper powder have twofold benefits:

1. Copper melts at 1,094°C, i.e. below sintering temperature, and rapidly infiltrates the pore system of the compact from where it diffuses relatively easily into the iron powder particles.

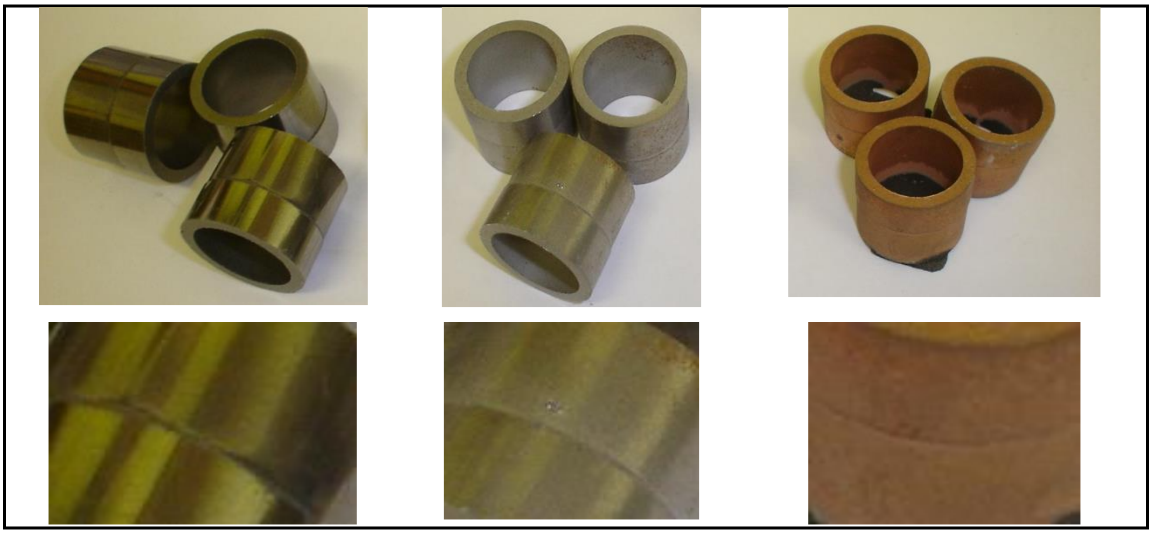
2. Copper is dissolvable in γ -iron (austenite) up to approx. 9 wt.-%, but only up to 0.4 wt.-% in α -iron (ferrite); consequently, iron-copper alloys can be precipitation-hardened by low-temperature annealing after sintering – and actually do so to a certain extend already on passing the cooling zone of the sintering furnace [9].

The mechanical properties of the parts are strongly related to the composition of the material. For tribological applications, the properties of the surface are linked to different metallic and intermetallic phases formed in the material [7]. In order to meet the requirements of future possible applications, it is important to improve the existing methods of enhancing the applied properties and develop new ones [10]. As the quality of the material powders and the manufacturing processes improved, powder metallurgy parts had in many cases taken the place of cast and forged products. It is very important in order to avoid subsequent operations such as sizing and machining, to improve the final dimensional tolerances obtained after sintering. There are many factors that cause dimensional changes, and their combined effect makes it more difficult to forecast and control these changes [7].

But it is clear that for tribological applications not only dimensional tolerance and properties of powder parts are very important, but also the quality of contact surface [11-13]. Surface condition of powder details at different stages of production of joining elements is the important factor that influences the choice of technological conditions of operations and end-use properties and running ability of the product. Generally, roughness, porosity and microstructure determine the surface condition. But mostly only the 2D surface roughness was investigated [3,7,11]. In the present paper, the experimental and theoretical results of the influence of the 3D surface roughness parameters of powder iron-copper details on the wear intensity are presented.

II. EXPERIMENTAL PART

The wear resistance of machine parts is one of the important characteristics making an impact on the quality of mechanical products. It defines the ability of surface layers to resist to the destruction as the result of machine parts rolling friction, sliding friction and vibration action [14]. The view of iron-copper details after different stages of production (compacting, sintering and infiltration) and macrostructures of surfaces are shown in Figure 4.



a) b) c)

Fig.4. Iron-copper details and macrophotography of surfaces after compacting (a), sintering (b) and infiltration (c): outer diameter 30 mm, inner diameter 26 mm.

For investigation the iron powder ASC 100.29 (Höganäs AB) with the following properties was used: apparent density 2.95 g/cm^3; flow 24 sec/50g; particle size from 40 to 60 µm; granite 0.5%; copper up to 2%. Micrograph of powder particles is given in the Figure 5.

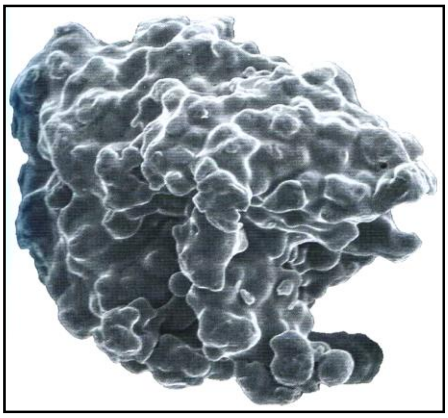


Fig.5. Micrograph of powder particles of the iron powder ASC 100.29 (powder producer: Höganäs AB, Sweden).

Iron-copper powder parts (Fig.4) were produced in the following steps:

1. Compacting was carried out on the hydraulic press in the closed die at the pressure up to 500 MPa. Density of the powder pars after compacting was up to 6.9 g/cm^3;
2. Sintering was realised in the endogas atmosphere at the temperature 1,120^{0}C, retention time 30 min. Sintered density of the parts was up to 7.1 g/cm^3, tensile strength 350 MPa, hardness HV10 98÷100, elongation 5.9 %.
3. Infiltration by copper melt were realised according to the technology given in [15]. Density of the powder pars was up to 8.2 g/cm^3, tensile strength 250 MPa, elongation 8.6%, copper content up to 12%.

Methodology for the investigation of the properties of powder parts, which was used in our investigation, is given in [16].

A. Measurement of 3D Surface Roughness

For exploring surface roughness the "Taylor Hobson Ltd" 3D measurement system has been used. This system is capable of dealing separately with roughness, waviness, summary surface and also showing them by means of graphical images. In our case 3D measurements with stylus instrument were achieved by basic "stepping" method and data processing by computer [17]. The achieved 3D surface image of the iron-copper detail after compacting sintering and infiltration is given in Figures 8, 9 and 10 respectively.

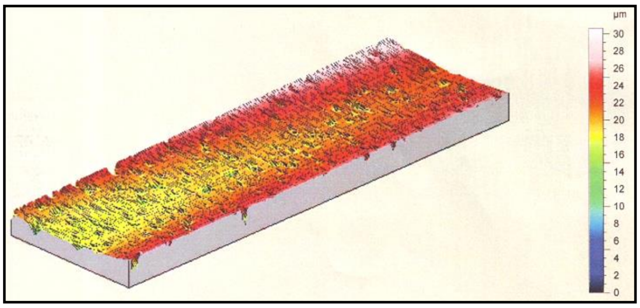


Fig.8. View of the 3D surface image of the iron-copper detail after compacting.

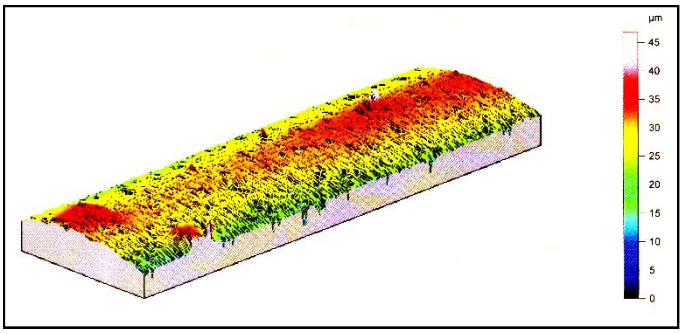


Fig.9. View of the 3D surface image of the iron-copper detail after sintering.

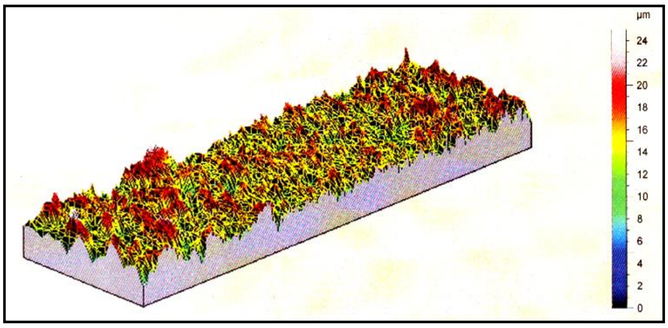


Fig.10. View of the 3D surface image of the iron-copper detail after infiltration.

For comparison we use amplitude parameters: *Sa* and *Sq* and spatial parameters: *Sds* and *Str* [18]. All these parameters are defined in comparison with a mean plane obtained through leveling of the mean square plane of the measured surface and then through centering of heights around the mean.

Sa – average absolute deviation of the surface. It should be calculated by the following formula:

$$Sa = \frac{1}{MN}\sum_{x=0}^{N-1}\sum_{y=0}^{M-1}\left|z_{x,y}\right|. \qquad (1)$$

Sq – root mean square deviation of the surface. Used to discriminate between different surfaces based on height information and to monitor manufacturing stability:

$$Sq = \sqrt{\frac{1}{MN}\sum_{x=0}^{N-1}\sum_{y=0}^{M-1}\left|z_{x,y}^{2}\right|}. \qquad (2)$$

Sds – density of summits of the surface. This parameter is used to evaluate the density of peaks and peats in the surface. This parameter is expressed in peaks/mm². A point is considered as a peak if it is higher than its 8 neighbors.

Str – texture aspect ratio of the surface. This parameter measures the isotropy of the surface. This parameter has a result between 0 and 1. If the value is near 1, we can say that the surface is isotropic, i.e. has the same characteristics in all directions. If the value is near 0, the surface is anisotropic, i.e. has an oriented and/or periodical structure. Comparison of the mentioned 3D parameters of iron-copper details after compacting, sintering and infiltration is given in Table 1.

TABLE I

COMPARISON OF AMPLITUDE AND SPATIAL 3D ROUGHNESS PARAMETERS

Iron-copper powder details after:	Amplitude parameters		Spatial parameters	
	Sa, µm	*Sq, µm*	*Sds, Pks/mm²*	*Str*
compacting	1.02	3.19	75.5	0.193
sintering	1.18	2.11	191.0	0.514
infiltration	2.0	2.6	218.0	0.547

As shown, at each step of the technological process the surface amplitude roughness parameters and spatial parameters increase as a rule. At the same time the parameter *Sq* (quadratic mean of the deviations from the mean) reduces after sintering. Especially significant changes occur with spatial parameters. Density of summits (*Sds*) increases three times during the stages of the technological process: compacting, sintering and infiltration. An important point is that at the same time the surface becomes more and more anisotropic since the value of parameter *Str* closer to 1. The reason for these changes of surface conditions is shrinkage of material during sintering and infiltration. So we can use measurement results not only for evaluation of details quality, but for prediction of shrinkage and consequently for pressing equipment design and choosing of sintering regimes.

B. Wear testing

Wear testing was carried out on friction and wear test machine, which realise a testing scheme “plane-disc” (Fig.11).

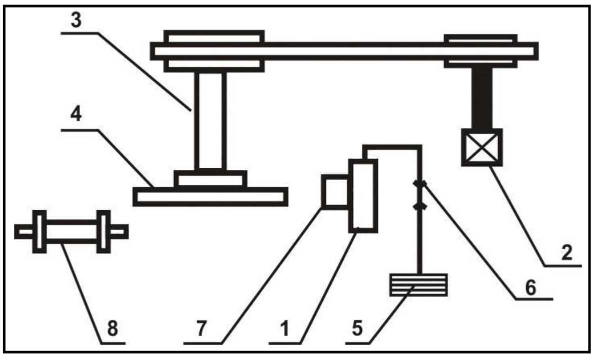


Fig.11. Kinematic scheme of friction and wear test machine: 1 - arm; 2 – engine; 3 – shaft; 4 – disc; 5 – loads; 6 – cable; 7 – sample; 8 – Brinell glass.

Diameter of disc was 50 mm, thickness 2 mm (steel 65Г with HRC 45....50), rotational speed was 880 min^{-1}, load 50 N. Wear testing was carried within collaboration with the Institute of Powder Metallurgy of the Belarusian State Research and Production Powder Metallurgy Concern. Linear wear intensity I_h was defined according to the methodology given in [19].

Experimental values were obtained as follows:

- ✓ For compacted samples: $I_h = 0.10{\cdot}10^{-8} \ldots 0.16{\cdot}10^{-8}$.
- ✓ For sintered samples: $I_h = 0.34{\cdot}10^{-8} \ldots 0.41{\cdot}10^{-8}$.
- ✓ For samples after infiltration: $I_h = 0.27{\cdot}10^{-7} \ldots 0.32{\cdot}10^{-7}$.

The worst result has been achieved for iron-copper powder details after infiltration, i.e. after final stage of production – the linear wear intensity is highest for the detail in comparison with the billet. It can be explained by the fact that the billet before infiltration contains only 1…2% of copper, but after infiltration – 8…12%. The range of the obtained data connected with the difference between powder parts was divided into groups according to copper content before infiltration and after infiltration. Increase of copper presence in powder details increases machinability, decreases friction coefficient, but increases the wear intensity. Consequently, the increase of copper content in iron-copper details decreases the durability, but nevertheless the achieved result of linear wear intensity ($0.27 \cdot 10^{-7}$ … $0.42 \cdot 10^{-7}$) show the possibility of successful use of such details for different applications in the industry.

III. CALCULATION OF WEAR INTENSITY

For engineering calculation of wear intensity the following methodology was used (proposed by the authors in [18]):

1. It is necessary to define the 3D surface roughness parameters and physical and mechanical properties of surface materials of wear parts;
2. Then the wear and fatigue characteristics have to be defined;
3. It is necessary to establish dimensional characteristics of wear parts design;
4. After analyzing the function conditions of wear parts the maximal allowable value of wear h_{max} should be set;
5. Then the wear rate I_h should be calculated according to the simplified equation for engineering calculations, which is valid for elastic contact of wear parts proposed in [18]:

$$I = k_F \cdot \left(\frac{Sa \cdot Str \cdot f}{Rsm_1 \cdot \sigma_0} \right)^t \cdot \Theta^{1-t} \cdot q \cdot Smr(c), \qquad (3)$$

where: $Str=Rsm_1/Rsm_2$ – texture aspect ratio of the surface; Rsm_1, Rsm_2 – mean width of the roughness profile elements in two orthogonal directions, µm ; f – friction coefficient; σ_0 – ultimate tensile strength at a single load cycle, MPa; t – exponent of frictional fatigue curve [20]; $Smr(c)=Ac/Aa$ – area material ratio of the scale limited surface, where Aa – nominal area of contact, m^2 and Ac – contour contact area, m^2; elastic constant of a material, MPa^{-1}, where E – Young's modulus, MPa and μ – Poisson's ratio; q – load, MPa; k_F – coefficient depending on Str and t [18].

The calculated wear intensity values are obtained as follows:

✓ For compacted samples: $I_h = 0.12 \cdot 10^{-8}$.

✓ For sintered samples: $I_h = 0.38 \cdot 10^{-8}$.

✓ For samples after infiltration: $I_h = 0.28 \cdot 10^{-7}$.

As it has been shown, calculated value of linear wear intensity is in close accordance with experimental data (maximal relative deviation is up to 20%, which is allowable deviation for engineering calculation). Calculations prove the results of experimental investigation: higher wear intensity is achieved for iron-copper powder details after infiltration, i.e. after the final stage of production.

IV. CONCLUSIONS

A brief review of the state and development of Powder Metallurgy has been given. Due to the demand for more cost effective powder materials, the iron-copper powder parts with different content of copper were examined in connection with possible tribological application.

The experimental and theoretical results of the influence of the 3D surface roughness parameters of powder iron-copper details on the wear intensity are presented. 3D surface roughness parameters were used as more adequate surface characteristics in comparison with 2D parameters. It was established that the values of amplitude and spatial parameters increase during the technological process: compacting, sintering and infiltration by copper of powder details. The reason for these changes of surface conditions is shrinkage of material during sintering and infiltration.

The linear wear intensity of powder details surfaces was calculated using the new approach previously offered by the authors. The new approach is based on the application of original contact criteria and probability theory. Analytical value achieved by using the simplified expression shows close accordance with the practical value. Higher linear wear intensity is achieved for iron-copper powder details after infiltration, i.e. after the final stage of production. Nevertheless, the achieved results show the possibility of successful use of such details for different applications in the industry, for example, for manufacturing of worm wheels or bearings.

REFERENCES

1. **T.Tsutsui**, *"Recent Technology of Powder Metallurgy and Applications"*, Hitachi Chemical Technical Report, No.54 (2012), pp.12-20.
2. **I.N.Popescu, V.Bratu, F.V.Anghelina, L.G.Toma** *"The Effect of Wear Test Parameters on Tribological Characteristics of Aluminium Based Composites"*, The Scientific Bulletin of Valahia University – Materials and Mechanics, Nr. 6 (year 9), 2011, pp.83-86.
3. **S.-Z.Chen, J.-H.Chern Lin and C.-P.Ju** "*Efect of Aluminum Content on Tribological Behavior of a Cu–Fe–C Based Friction Material Sliding against FC30 Cast Iron"*, Materials Transactions, Vol. 44, No. 4 (2003), pp.787-793.
4. **A.Ilyushchenko, V.Savich** *"Powder Metalllrgy in Belarus: Overview 2008-2013"*, In Proceedings of 8th International Scientific Conference "Materials, Environment, Technology MET-2013", 19-20 June 2013, Riga, Latvia, pp.20-29.
5. **F.A.Sadykov, N.P.Barykin, I.R.Aslanyan** *"Wear of copper and its alloys with submicrocristalline structure"*, Wear, 1999, V.225-229, pp.649-655.
6. **C.Teisanu, A.Tudor, S.Gheorghe, I.Ciupitu** *"Tribological Features of PM Iron-Copper Based Materials"*, The Annals of University "Dunarea de Jos": Tribology, 2003 (VIII), pp.168-172.
7. **C.Teisanu, S.Gheorghe** *"Development of New PM Iron-Based Materials for Self-Lubricating Bearings"*, Hindawi Publishing Corporation, Advances in Tribology, Volume 2011, 11 p.
8. **Z.Shi, P.Jian, P.Xue, D.Chen** *"The Friction and Wear Characteristic of Iron-based Powder Metallurgy Materials in Scroll Compressor"*, In Proceedings of 21st International Compressor Engineering Conference at Purdue, West Lafayette, Indiana, USA, July 16-19, 2012, 6 p.
9. "Sintered Iron-Based Materials", Höganäs PM-school, Chapter No.9. Available: http://riad.pk.edu.pl/~mnykiel/iim/KTM/ [May 20, 2013].

10. **C.Teisanu, S.Gheorghe, A.Tudor, I.Ciupitu** *"The Influence of the Applied Load on the Friction Coefficient of Sintered Iron-base Bearings",* The Annals un University "Dunarea de Jos": Tribology, 2008 (XIV), pp.65-68.
11. **J.W.Kaczmar, K.Granat, E.Grodzka, A.Kurzawa** *"Tribological Properties of Cu Based Composite Materials Strengthened with Al_2O_3 Particles"*, Archives of Foundry Engineering, Vol.13, Special Issue 2 (2013), pp.33-36.
12. **C.Yang** *"Role of Surface Roughness in Tribology: from Atomic to Macroscopic Scale",* Key Technologies Band, Volume 7 (2008), 166 p.
13. **A.Y.Suh, A.A.Polycarpou, T.F.Conry** *"Detailed Surface Roughness Characterization of Engineering Surfaces Undergoing Tribological Testing Leading to Scuffing"*, Wear, Vol.256, Issues 1-6, pp. 556-558.
14. **E.Napalkov, O.Lininsh** *"Method for Calculating the Friction Surfaces Wear Based on Multi-Parametrical Optimisation",* In Proceedings of 15th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT 2011, Prague, Czech Republic, 12-18 September 2011, pp.753-756.
15. **W.Schatt, K-P.Wieters, B.Kiemack** *„Pulvermetallurgie: Technologien und Werkstoffe"*, Springer, 2006, 552 p.
16. **L.N.Dyachkova, L.F.Kerzhentseva, L.V.Markova** *"Powder iron-based materials"*, Minsk, 2004, 228 p. (*in Russian*)
17. "Exploring Surface Texture" 4th Edition Leicester, Taylor Hobson Ltd. (2003).
18. **O.Linins, J.Krizbergs, I.Boiko** *„Wear Estimation using 3D Surface Roughness Parameters",* Key Engineering Materials, Engineering Materials and Tribology, Vol. 527 (2013), pp. 167-172.
19. **V.V.Savich, L.N.Dyachkova, N.A. Shipitsa** "*Sintered Powder Materials: Methods and Equipment for Investigation of the Properties of Initial Powders, and of Structure and Technological Properties of Powder Details"*, Minsk, Belarus, Geoprint, 2008. (*in Russian*)
20. **I.Kragelsky, V.Alisin, Tribology** – *Lubrication, Friction and Wear,* Mir publishers, Moscow, 2001. (*in Russian*)

Irina Boiko graduated from Riga Technical University in 1993, where she received a Bachelor Degree in Engineering. In 1994 she was qualified as a Mechanical Engineer in Precision Mechanical Engineering. She obtained a Master's Degree in Engineering Science at RTU in 1997, but in 2002 – the degree of Doctor of Engineering Science (Dr.sc.ing.). In 2007 she was qualified as European Welding Engineer (EWE) and International Welding Engineer (IWE) by DVS Perszert, Germany. Fields of expertise: Mechanical Engineering, particularly Welding Technology; Material Engineering.

Scientific work started in 1996, but pedagogical work at RTU – in 2002. Since 2010 she holds a title of associate professor of Riga Technical University.

From 2011 she is a member of the board of Association of Mechanical Engineering and Metalworking Industries of Latvia. From 2008 to 2012 she was the Chair of the Board of Latvian Welding Specialists Society.

Oskars Lininsh graduated from Riga Polytechnic Institute (now RTU) in 1965, where he got an engineering degree in production technology. He obtained a PhD Engineering Degree in the field of friction and wear in machines at RTU in 1992.

His scientific work started in 1966, when he worked as an assistant at Riga Polytechnic Institute. From 1970 the author started his pedagogical work and since 1973 he continued as a professor assistant in Riga Technical University. In 2001 he was elected associate professor and in 2008 – a professor at RTU Institute of Machine Building. At the same time he worked as the Secretary of Science in the Commission of Production Technology and currently he is the Secretary of the Council of the Faculty of Transport and Mechanical Engineering

The main research fields are calculations of friction and wear in machines and design of apparatuses.

Viktors Mironovs graduated from Technical University of Tver (Faculty of Mechanical Engineering), Russia, in 1965, where he got an engineer qualification. In 1972 he obtained Dr.sc.ing. degree (Candidate of Engineering Science in USSR) at Riga Polytechnic Institute (now RTU), but in 1986 he got a Dr.habil.sc.ing. degree (Doctor of Engineering Science in USSR), Moscow, Russia.

Scientific work started in 1970, when he worked as a researcher and engineer at the Welding Laboratory of Riga Polytechnic Institute. At the same time the author started his pedagogical work and since 1999 he continued as professor at Riga Technical University. From 1975 onwards he is the Head of Powder Materials Laboratory of RTU. Main scientific fields: Electromagnetic Pulse Technology; Powder and Composite Materials; Environmental Technologies and Tools and Building Machines.

From 1989 to 2004 he was a member of the Board of Latvian Welding Research Society. From 1984-1996 he was the Head of Inventor Society of Riga Technical University. Since 1998 he is a member of the Board of Material Research Society of Latvia. In 1982 he received the award 'Inventor of Latvia'. In 2009 he was awarded the title the Teacher of the Year, Riga Technical University.

Andris Kamols graduated from Riga Polytechnic Institute (now RTU) in 1972, where he got an engineer degree in machine building. He got a PhD science engineering degree in the field of production of friction and wear in machines at RTU in 1992.

Scientific work started at Riga Polytechnic Institute in 1976. From 1976 the author started his pedagogical work at Riga Technical University and since 1994 he continued as an assistant professor. Since 2001 he is an associate professor at Riga Technical University, the Institute of Machine Building. The author of many books and study aids connected with design, engineer drawing, tribology, production engineering.

The main scientific interests: contact of sliding friction pair and wear.

Irina Boiko, Oskars Liniņš, Viktors Mironovs, Andris Kamols. 3D virsmas raupjuma parametru ietekme uz dzelzs-vara pulverdetaļu nodiluma intensitāti

Raksta mērķis ir novērtēt 3D virsmas raupjuma parametru ietekmi uz dzelzs-vara pulverdetaļu nodiluma intensitāti. Pētījumā tika izmantotas detaļas no dzelzs pulvera ASC 100.29 (ražotājs: Höganäs AB, Zviedrija), kas pēc infiltrēšanas saturēja no 8 līdz 12% vara. Tika veikti gan eksperimentālie, gan teorētiskie pētījumi. Ir atklāts, ka 3D raupjuma parametru vērtības (amplitūdas un soļa parametri) pieaug līdzi detaļu izgatavošanas tehnoloģiskam procesam: presēšanas, saķepināšanas un infiltrēšanas ar varu. Viens no iemesliem tādām virsmas stāvokļa izmaiņām ir materiāla rukums saķepināšanas un infiltrēšanas laikā. Iegūtas analītiskās lineārās diluma intensitātes vērtības ir tuvas eksperimentālajiem datiem. Lielāka diluma intensitāte ir raksturīga pulverdetaļām pēc infiltrēšanas, t.i., pēc izgatavošanas pēdēja etapa. Tomēr iegūtie rezultāti parāda iespēju efektīvi pielietot dzelzs-vara pulverdetaļas vairākos rūpnieciskos pielietojumos, piemēram, gultņu vai gliemežratu izgatavošanai.

Ирина Бойко, Оскарс Лининьш, Виктор Миронов, Андрис Камолс. Влияние 3Д параметров шероховатости на интенсивность износа железо-медных порошковых деталей.

Целью настоящей статьи является оценка влияния 3Д параметров шероховатости на интенсивность износа железо-медных порошковых деталей. В исследованиях были использованы детали, изготовленные их железного порошка ASC 100.29 (изготовитель: Höganäs AB, Швеция), после инфильтрации расплавом на основе меди, содержащим медь от 8 до 12%. Были проведены как экспериментальные, так и теоретические исследования. Установлено, что значения 3Д параметров шероховатости возрастают в течение технологического процесса: прессовки, спекания и инфильтрации медью. Одной из причин этого является усадка матерuла во время спекания и инфильтрации. Полученные аналитические величины интенсивности линейного износа хорошо согласуются с данными экспериментов. Наибольшая интенсивность изнашивания характерна порошковым деталям после инфильтрации – последнего этапа их изготовления. Однако полученные результаты показали возможность их использования для различного промышленного применения, например, для изготовления подшипников или для червячных колес.