Influence of the pressing force on the strength properties of sintered materials based on water-dispersed iron powders alloyed with copper

Ivanka Miteva, Ivan Mitev, Toschko Kovachev
Technical University Gabrovo, 14. Hadgi Dimitar Str. Bulgaria
idmiteva_prestij@abv.bg

Abstract: *In this publication we study the influence of the pressing force on the strength characteristics of sintered materials based on water - dispersed iron powders alloyed with copper. Three brands of iron powders were studied - AHC 100.29, ASC 100.29 and ABC 100.30, to which 2 and 4% electrolytic copper were added. After pressing with a force of 300 ÷ 800 MPa, they were sintered at a temperature of 1150 ° C for 1 h. Experiments were performed to determine three strength characteristics - tensile strength, yield strength, elongation. In determining the mechanical characteristics in order to prevent the influence of porosity, five measurements were made for each type of samples, and in the graphical interpretation of the results the arithmetic mean values were used.*
Keywords: *WOTER DISPERSED IRON POWDER, COPPER, TENSILE STRENGTH, YIELD STRENGTH, RELATIVE ELONGATION*

1. Introduction

Significant increase of the mechanical properties of the sintered materials with structural purpose is achieved by alloying the iron matrix with copper, nickel, chromium, molybdenum, tungsten and others elements. [2,3,4] Of the listed elements, copper is most often used for alloying structural sintered materials. At the sintering temperature it is in a liquid state [10,11,12] which helps to intensify the processes of coagulation of the pores, has a graphitizing effect, reduces the critical rate of hardening and thus increases the hardenability of the material and improves compressibility.

In ferro-copper alloys used in powder metallurgy, the concentration of copper varies in a relatively wide range - 0.5 ÷ 25% [4,10,12].

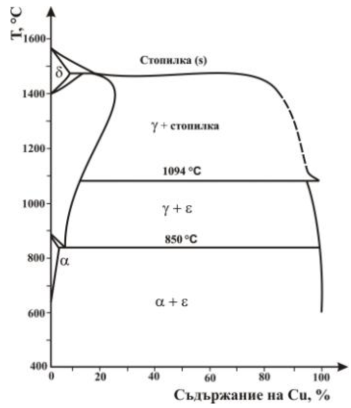


Fig.1. *Diagram of the state of the iron-copper system [12]*

Based on the state diagram of the binary system Fe-Cu - Fig.1, we can conclude that at such concentrations of copper in the iron matrix liquid phase in sintering the products can be realized only at temperatures higher than 1094ºC. At this sintering temperature, up to 7.0% Cu can be dissolved in the Feγ lattice. At copper concentrations above these percentages, the two-phase mixture of copper-rich solid solution and Feγ is equilibrium.

It follows from the diagram that in case of pre-mixed iron and copper powders in arbitrary concentrations when heated above 1094ºC, as a result of the formation of a liquid phase on the partition surface between the iron particles and copper there are conditions for sintering in the presence of liquid phase. After cooling, a significant amount of copper remains at low temperatures in the precipitated α solid solution and, with subsequent aging, leads to the strengthening of the alloys by the separation of the ε - phase.[12]

In the present study, the aim is to trace the influence of the pressing force and the concentration of copper on the strength characteristics of iron samples based on water-dispersed powders [6,8] type ANS 100.29, ASC 100.29 and ABC 100.30.

2. Experimental results

Three brands of iron powders were tested - ABC 100.30, AHC 100.29 and ASC 100.29. They are obtained by aqueous dispersion of a melt of iron scrub heated to temperatures of 16540 ÷ 1700ºC. Nozzles with a diameter of 14 ÷ 16mm were used for spraying.

After spraying, the main technological properties of iron powders are determined, which are presented in Table №1.

Table 1: *Technological properties of iron powders*

Powder mark	Max. particle size, μm	Apparent density $.10^3$kg/m^3	Flowa-bility, s	Compaction at 420MPa, $.10^3$kg/m^3	Max. O_2, %	Max. C, %
AHC 100.29	170	2,98	25	6,91	0,10 0,20	0,01 0,02
ASC 100.29	170	2,98	25	6,82	0,10 0,15	0,01 0,02
ABC 100.30	170	3,00	25	6,75	0,10 0,15	0,01 0,02

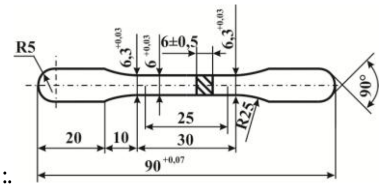
The iron matrix of the tested samples was alloyed with 2 and 4% electrolyte copper with chemical composition according to table 2.

Table 2: *Chemical composition of copper powder*

Chemical composition, %			
Cu	O_2	H_2O	Fe
99,5÷99,8	0,10÷0,30	0,05	≤0,02
Pb	Sb	SO_4^{-2}	други
≤0,05	≤0,01	≤0,01	≤0,05

After homogenization of the powders, they are pressed with a force of 300 ÷ 800 MPa. When pressing the samples to improve the compaction, 8% Lubricated PS plasticizer was added. [1,7] The samples thus formed were sintered at 1150°C in a dissociated ammonia medium for 1 hour.

The strength characteristics tests were performed according to EN 10045-1 on a universal testing machine ZD 40PU, with a range of applied force in the range of 100 ÷ 1000kN. During the tests, specially made test bodies for powder metallurgical materials according to BDS 1086-88, with a rectangular cross section, with an area of 700mm^2 and basic dimensions according to Fig. 2 were used.[5,9]



:.

Fig.2. *Drawing of a test tube of powder material to study tensile strength*

In order to prevent the influence of the porosity in determining the strength characteristics, five measurements were made for each type of samples, and the arithmetic mean values are plotted in the tables.

The experimental results in determining the tensile strength are presented in Table 3, and for the yield strength and elongation in Tables 4 and 5, respectively. For comparability of the experimental results, similar studies were performed in parallel on samples of pure iron.

The graphical interpretation of the results obtained in the experiments is presented in fig. 3 ÷ 11.

From the obtained experimental results it can be seen that for the samples of pure iron with small pressing forces - 300 ÷ 400 MPa the values for the tensile strength are of the order of 150 ÷ 170 MPa. As the pressing force increases as a result of the reduced porosity in the samples, their tensile strength increases by 40 ÷ 50%, reaching values of 220 ÷ 260 MPa. In this case, the change in the tensile strength values is only due to the reduced porosity, the increased surface contact between the particles and the increased density of the samples. This increase is most significant in samples of iron powder ANC100.29 - 56%, which is explained by their better formability compared to the other tested powders.

Table 3: *Experimental results for tensile strength, MPa*

Brand iron powder	Pressing force, MPa					
	300	400	500	600	700	800
	Tensile strength – Rm,MPa					
	100%Fe					
AHC 100.29	169	187	196	222	248	264
ASC 100.29	151	164	182	194	214	222
ABC 100.30	157	171	193	203	208	218
	Fe + 2,0%Cu					
AHC 100.29	196	212	233	241	275	284
ASC 100.29	218	231	264	278	286	298
ABC 100.30	207	227	251	278	284	299
	Fe + 4,0%Cu					
AHC 100.29	228	244	262	273	305	322
ASC 100.29	236	255	270	274	292	308
ABC 100.30	219	239	248	266	271	296

Table 4: *Experimental results for yield strength, MPa*

Brand iron powder	Pressing force, MPa					
	300	400	500	600	700	800
	Yield strength – Reh, MPa					
	100%Fe					
AHC 100.29	93	107	114	123	136	148
ASC 100.29	77	83	88	92	98	101
ABC 100.30	65	76	80	87	90	96
	Fe + 2,0%Cu					
AHC 100.29	158	171	179	188	195	209
ASC 100.29	162	178	195	217	219	231
ABC 100.30	154	164	171	176	196	202
	Fe + 4,0%Cu					
AHC 100.29	189	205	223	239	268	284
ASC 100.29	177	185	205	226	234	242
ABC 100.30	166	176	184	197	218	227

Table 5: *Experimental results for relative elongation,%*

Brand iron powder	Pressing force, MPa					
	300	400	500	600	700	800
	Relative elongation – ε, %					
	100%Fe					
AHC 100.29	8,10	9,30	10,42	11,67	12,97	14,74
ASC 100.29	9,94	12,38	15,38	17,87	18,44	19,43
ABC 100.30	17,21	18,35	20,15	21,54	22,02	22,13
	Fe + 2,0%Cu					
AHC 100.29	3,08	4,12	4,86	5,44	6,06	6,21
ASC 100.29	4,98	6,45	7,69	10,13	12,16	13,69
ABC 100.30	7,11	8,54	10,32	12,53	13,68	14,13
	Fe + 4,0%Cu					
AHC 100.29	1,03	1,78	1,84	1,97	2,04	2,15
ASC 100.29	1,87	3,14	4,05	4,86	4,96	5,87
ABC 100.30	3,72	4,56	5,04	5,17	5,98	6,57

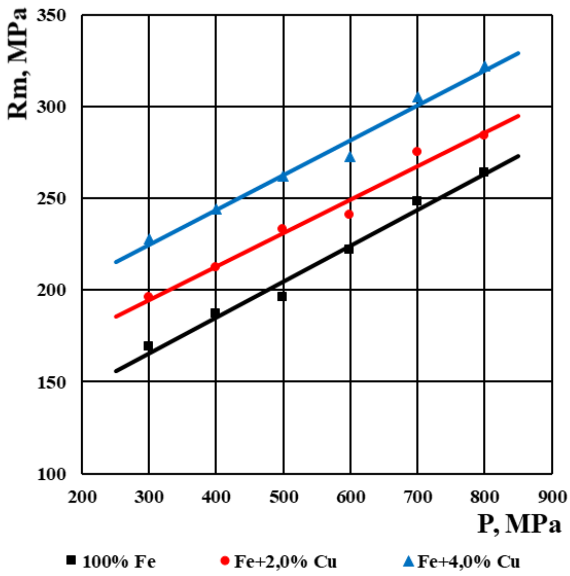


Fig. 3. *Tensile strength for matrix specimens of iron powder AHC100.29*

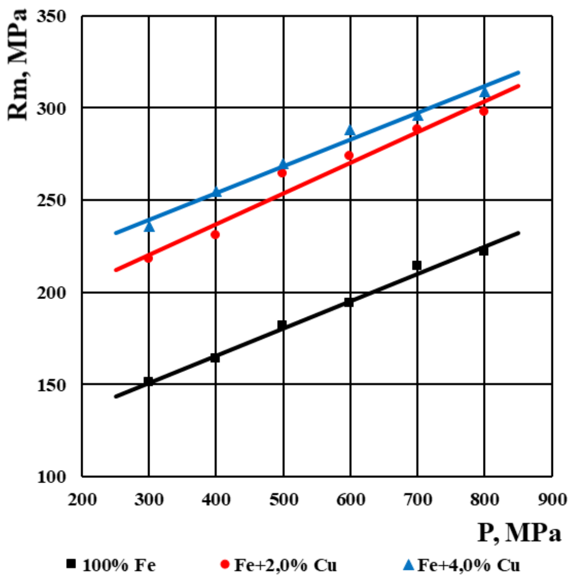


Fig. 4. *Tensile strength for matrix specimens of iron powder ASC100.29*

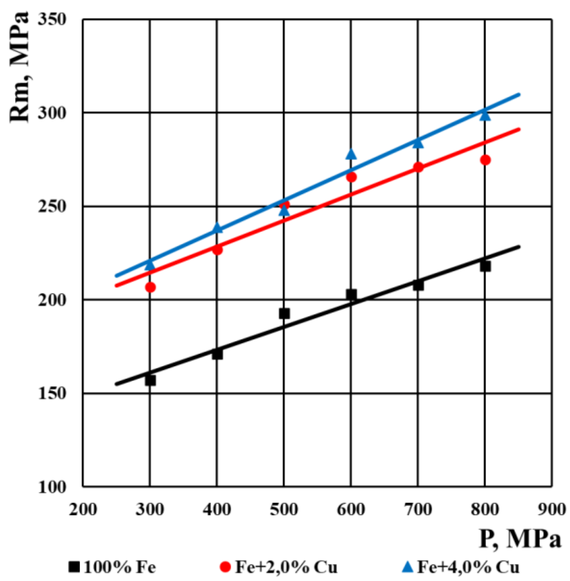


Fig. 5. *Tensile strength for matrix specimens of iron powder ABC100.30*

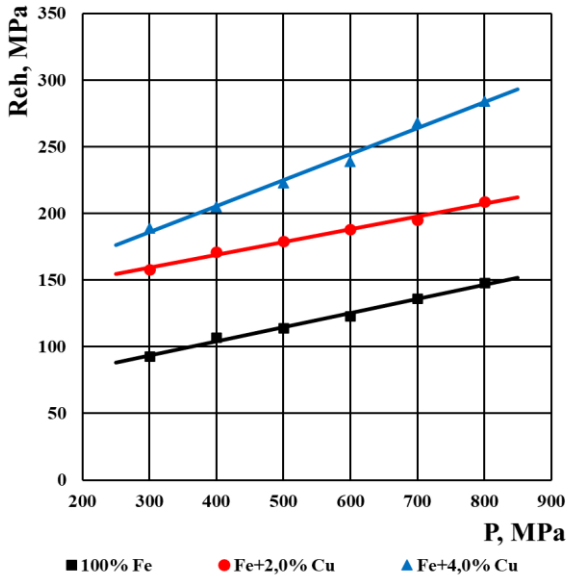


Fig.6. *Yield strength for samples with a matrix of iron powder AHC 100.29*

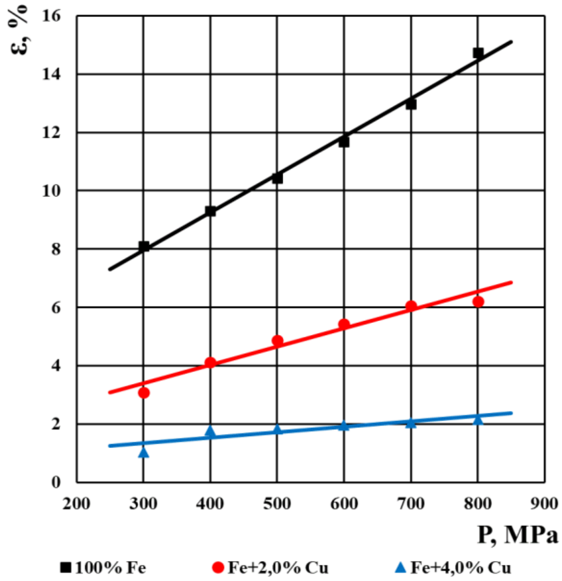


Fig. 9. *Relative elongation for matrix samples of iron powder AHC 100.29*

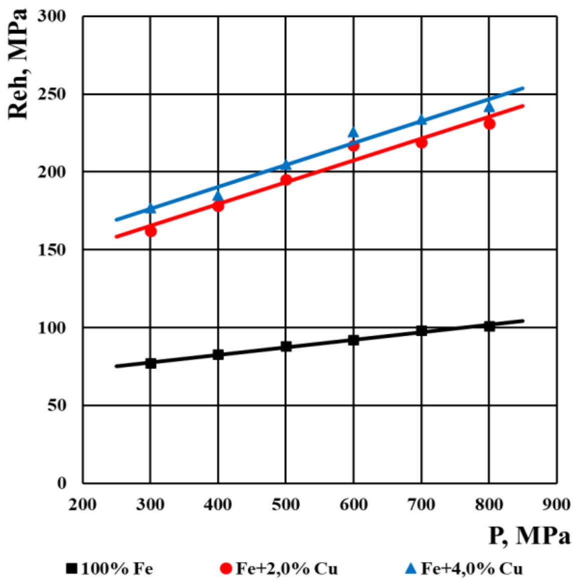


Fig.7. *Yield strength for samples with a matrix of iron powder ASC 100.29*

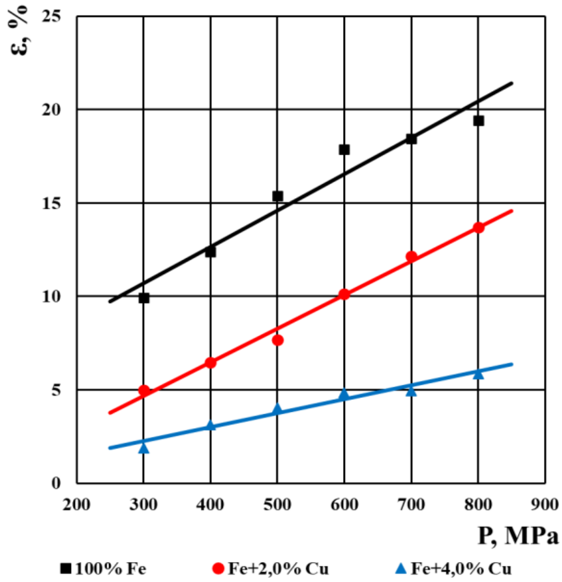


Fig. 10. *Relative elongation for matrix samples of iron powder ASC 100.29*

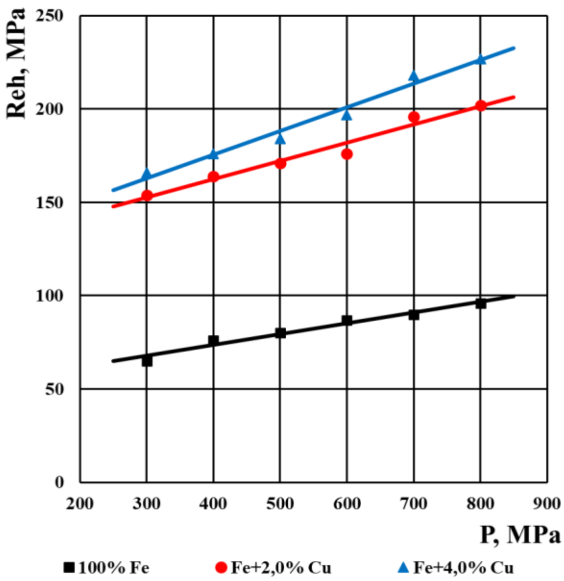


Fig.8. *Yield strength for samples with a matrix of iron powder ABC 100.30*

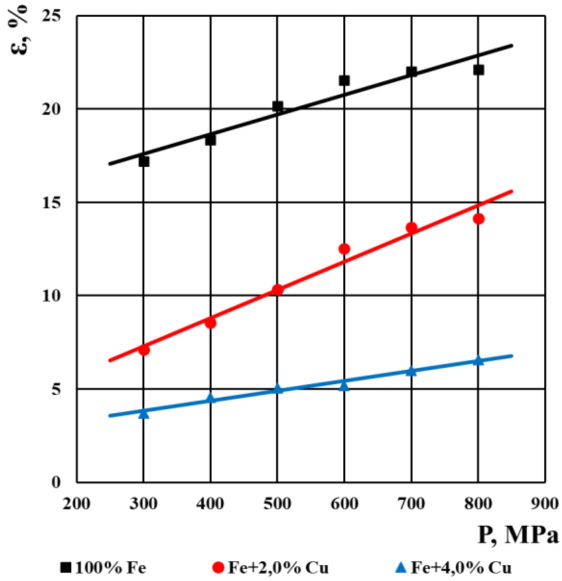


Fig. 11. *Relative elongation for matrix samples of iron powder ABC 100.30*

The addition of 2.0 ÷ 4.0% copper in the iron matrix allows at the sintering temperature - 1150ºC, the process to be realized in the presence of a liquid phase in the iron matrix. This favors the coalition of the pores and leads to a significant change in the values of the closed porosity. This has a positive effect on the tensile strength after sintering, as its values increase by 60 ÷ 85 MPa regardless of the compression force. The highest values for the tensile strength are registered for samples alloyed with 4.0% copper.

The experimental results obtained in the study of the yield strength are similar. For samples of pure iron at low values of the pressing force, the results vary in a relatively narrow range of 65 ÷ 90 MPa. As the pressing force increases as a result of the reduced porosity, the values for the yield strength increase, as this increase is most significant in samples of iron powder ANC 100.29 - 55MPa, and in samples of iron powder ASC 100.29 and ABC 100.30 is respectively 25 and 30MPa. The addition of copper to the iron matrix leads to a significant increase in the values for the yield strength and despite the pressing force at a concentration of 4.0% copper in the iron matrix the values for the yield strength increase more than twice.

In structural details, the relative elongation is an essential mechanical characteristic that determines the behavior of the material, both in the process of operation and at different temperature influences. The changes in the values for the tensile strength and the yield strength registered above have a significant influence on the values for the relative elongation of the tested samples. From the obtained graphical dependences - fig.9 ÷ 11, it can be seen that they are highest in samples made of pure iron. They have a ferrite structure. Ferrite is a plastic phase, which allows the relative elongation to have high values. At low values of the pressing force 300 ÷ 400 MPa, depending on the type of iron powder, the relative elongation of the tested samples varies in the range of 10 ÷ 17%. The highest results are for samples of iron powder ABC 100.30 - 17%, and for other iron powders vary in the range of 8 ÷ 10%. As the pressing force increases to 800 MPa, the values for the relative elongation of the pure iron samples almost double and are of the order of 15 ÷ 22%. The addition of copper to the iron matrix increases the strength of the specimens, but this leads to a decrease in their relative elongation results. When pressing iron samples alloyed with 4.0% copper with a force of 300 ÷ 400 MPa, this decrease is 5 ÷ 8 times, and when pressing with a force of 800 MPa - 3 ÷ 7 times, the values varying respectively in the intervals 1.03 ÷ 3.72 % and 2.15 ÷ 6.55%.

3.Conclution

The following more important conclusions can be formulated from the conducted researches and the obtained results:

- It was confirmed that with increasing compressive force the density of the samples increases (decreases the amount of internal porosity) as a result of which the tensile strength and the yield strength of the samples of pure iron increases. This increase is most significant - 56%, in samples of iron powder ANC 100.29, which is explained by their better formability compared to iron powders type ASC 100.29 and ABC 100.30.

- It has been confirmed that the addition of electrolytic copper to the iron matrix leads to the formation of a liquid phase in the sintering process at 1150 ° C. This accelerates the process of coalescence of the pores, reduces the relative porosity in the iron matrix and increases the tensile strength by 60 ÷ 85 MPa regardless of the compression force.

- The highest values for the tensile strength, regardless of the type of iron powder used, are registered for samples alloyed with 4.0% copper and pressing force 800 MPa - 300 ÷ 320 MPa.

- It was confirmed that the tensile strength is directly dependent on the yield strength of the samples. For samples of pure iron, regardless of the pressing force and the type of iron dust, the values for the yield strength are 40 ÷ 55% of the values for the tensile strength. .

- The addition of copper to the iron matrix improves the ductility of the samples. As a result, an increase in the values for the limit of proportionality is registered, as in samples alloyed with 4.0% copper they reach 75 ÷ 90% of the values for the tensile strength.

- It was found that the values for the relative elongation are the highest in the samples of pure iron, as they have a pure ferritic structure and very high ductility. Depending on the pressing force, they vary in the range of 8.5 ÷ 22.0%, as the lower values are for samples pressed with a force of 300 MPa, and the higher values for samples pressed with a force of 800 MPa.

- The addition of copper to the iron matrix has been shown to increase the strength of the specimens, but this leads to a decrease in their elongation results. When pressing iron samples alloyed with 4.0% copper with a force of 300 ÷ 400 MPa, this decrease is 5 ÷ 8 times, and when pressing with a force of 800 MPa - 3 ÷ 7 times, the values varying respectively in the intervals 1.03 ÷ 3.72 % and 2.15 ÷ 6.55%

4. References

1. Kovachev, J., I. Miteva**,** I. Mitev, Influence of Pressure Force on Density Before sintering of Iron Powder Materials Obtained by Reduction, AJ Industrial Technologies, Issue7/2020, ISSN 1314-9911, pp. 23÷27.
2.Mitev, I. N, Industrial Materials, ECS-PRESS, Gabrovo, 2017, ISBN 978-954-490-556.
3. Mitev, I., Modern Industrial Technologies - Part III (Progressive Methods for Mechanical Formation), ECS-PRESS, Gabrovo, 2016, ISBN 978-954-490-511-8.
4. Mitev, I., Powder Metallurgy - Part I (Obtaining Powder Metallurgical Materials and Products,) UP „V.Aprilov", Gabrovo, 2004, ISBN 954-4683-233-2.
5. Mitev, I., Structural Analysis, EX-PRESS, Gabrovo, 2013, ISBN 978-954-490-363-3
6. Miteva, I., Perculiarities of the technological process in the preparation of metal powders, IJSTII „Machines technologies materials", year XIV, Issue 2/2020, pp.93÷95 ISSN 1313-0226.
7. Mitev,I., I.Todorova**,** Dimension Changes of Iron Powder Materials Alloy with Phosphoru Depending on the Process Parameters During Sintering, IJSTII Machines Technologies Materials, year XI, Issue 4/2017, ISSN print 1313-0226, ISSN web 1314-507X, pp. 198÷202
8.Mitev,I**.,** Influence of the Type of Iron Powder of the Tensile Strength of Iron Carbon Powder Materials Alloyed with Cooper, International Journal of Engineering and Advanced Technology (IJEAT), Volume 4, Issue 4, 2015, pp.156÷159, ISSN (online) 2249-8958.
9.Mitev,I., R.Maimarev, Optimizing Strength Characteristics of Powder Workpieces of Fe-C-Cu System, International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS), ISSUE 5, vol.1, 2013, p.1÷6, ISSN (online) 2279-0055, ISSN (print) 2279-0047
10. Mitev, I., R. Maimarev, Sintering of two-component powder construction materials in the presence of liquid phase, Mechanical Engineering and Mechanical Engineering, book №17, 2012, p.70 ÷ 73, ISSN 1312-8612.
11. Mitev, I., Technologies for chipless forming, EX-PRESS, Gabrovo, 2021, ISBN 978-954-490-492-6.
12. Mitev, I., Copper in two-component powder metallurgical systems, EX-PRESS, Gabrovo, 2019, ISBN 978-954-490-632-0