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Tensile Strength of Copper Alloyed Structural Powder Steels

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***Abstract*— The publication traces the influence of the type of iron powder and the sintering process in the presence of a liquid phase on the tensile strength of powder metallurgical samples from the Fe-C-Cu system. Powder metallurgical samples of three types of iron powders – ASC 100.29, SC 100.26 and NC 100.2 – were studied. The iron matrix is alloyed with 2.5%Cu and 0.2÷0.8%C. After sintering, their density is in the range of 6.20÷7.00g/cm3. Graphical dependences for the change in tensile strength depending on the density of the samples and the concentration of carbon and copper in them are presented.**

Keywords*— *copper, density, liquid sintering, powder metallurgy, tensile strength.

I. Introduction

One of the main technologies that fully meets the requirements of Industry 4.0 and Industry 5.0 for zero waste and environmental friendliness is powder metallurgy [1, 2, 3, 4, 5, 6, 7, 8]

In the most general sense, powder metallurgy technology consists of three stages - mixing the starting powders, pressing them into the desired shape and subsequent sintering [9, 10].

Sintering is a type of heat treatment to which pressed blanks are subjected in order to acquire a complex of physical and mechanical properties. A characteristic feature of this process is that it is carried out at temperatures 0.7÷0.9 of the melting temperature of the most easily fusible component in the alloy. The effectiveness of the process is judged by the strength, plasticity, specific electrical resistance, density, etc. properties of the sintered bodies. [11, 12, 13, 14, 15].

The main thermodynamic factor in the case of sintering of pure metals is the pursuit of minimal surface free energy, and in multicomponent systems the additional decrease in chemical free energy. The kinetics of densification of the samples is thermally activated and predetermined by the operating mechanisms of mass transfer in the sintered matrices, such as bulk, surface and boundary diffusion, evaporation, condensation, etc. [16]

Although usually the sintering processes in powder metallurgy are realized in the solid state, often to increase their efficiency resort is made to sintering in the presence of a liquid phase [17]. Sintering in the presence of a liquid phase is carried out in cases when there is a fusible component in the charge or in the sintering process a eutectic is formed. The amount of the liquid phase in these cases must be significantly less than that of the solid phase, otherwise distortion of the shape is possible in the sintering process [18, 19].

Copper is most often used as a source of liquid phase. Copper is an element that is not used in conventional metallurgy, but it has a number of features that favor its use in powder metallurgy. The most important of them are [20, 21, 22, 23, 24, 25]:

- can be obtained in the form of powder using various technologies;
- the resulting copper particles can be of different shapes;
- has easily recoverable oxides;
- high plasticity which facilitates pressing;
- lower melting point than Fe which determines sintering in the presence of a liquid phase, etc.

In this study, the influence of the type of iron powder on the flexural strength values of the most commonly used in practice two-component system with limited solubility Fe-C, after sintering in the presence of a liquid phase – Cu, was monitored.

II.Materials and Metods

The main mechanical characteristics of the sintered iron products used in practice are directly dependent on the shape and size of the starting powder particles. Based on the literature data on the application and characteristics of the most commonly used iron powders in powder metallurgy [26, 27, 28, 29], the following main conclusions can be formulated:

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- Reduced sponge iron powders are used primarily in cases where the products do not require particularly high compaction - in antifriction products. Their application is mandatory when high raw strength requirements are imposed on the final product, as is the case with friction materials, long and thin parts, etc.;
- Products with medium density can be made from both sponge and water-dispersed iron powders. The choice of powder for them is made based on the requirements for each specific case;
- In the production of high-density products, water-dispersed iron powders with high compaction and purity are used. These powders are also used in the production of soft magnetic and hot-forged products because they contain fewer impurities.

Based on these conclusions, we have selected three types of iron powders produced by the company "Höganäs" - Sweden - NC100.24; SC 100.26 and ASC 100.29 for research [30].

NC 100.24 is one of the most widely used iron powders obtained by the reduction method in the practice of powder metallurgy. Its compactability is very good, and thanks to the spongy structure of the particles, their formability is very high. The raw (after pressing) and final (after sintering) strength of parts made from these powders is very high, and the concentration of hydrogen in them is low [31].

The best compactability of all sponge iron powders produced by the company "Höganäs" by the reduction method is the iron powder type SC 100.26. This makes it particularly suitable for the production of parts with a single pressing for which there are requirements for higher density. Similar to the powders of the previous type, these have high raw strength, but a slightly higher density than them. They are recommended for the production of parts that will subsequently be subjected to chemical-thermal treatment [32, 33].

Iron powder ASC 100.29 is a representative of the group of water-dispersed powders. At the moment, this is the highest quality iron powder produced by the company "Höganäs". It is distinguished by very high purity. It has excellent compactability, which is a result of the particles being almost spherical in shape. This allows, after a single pressing, to achieve a density of the order of 7.20÷7.3g/cm^3. These powders are particularly suitable for the production of high-density structural products, as well as for products with certain magnetic characteristics. The maximum size of the fractions of the iron powders used, their compactability at a force of 420MPa, as well as the concentration of oxygen and carbon in them are presented in table 1.

TABLE 1 IRON PULDERS

Type Fe powder / max. size, **μm**	Sealability at **420MPa**		O_2, %	C, %
	averagea	min.	max.	max.
NC 100.24/150	6,45	6,40	0,30	0,02
SC 100.26/150	6,65	6,63	0,15	0,01
ASC100.29/170	6,82		0,15	0,02

The main mechanical characteristics of structural powder metallurgical materials in the process of their exploitation is their tensile strength. In its study, samples with a chemical composition corresponding to the results obtained during the quantitative optimization of the elements of the ternary system were used. The percentage content of copper in the samples is 2.5÷2.6%, and the amount of carbon varies within 0.2% within the limits of 0.2÷0.8%.

The studied samples were made according to the methodology developed in [34, 35, 36], and their pressing was carried out with a force of the order of 300÷700MPa. This allows them to have different densities after sintering at 1150°C in a dissociated ammonia environment. Their mass after mixing was determined so that after pressing and sintering their density was within the range of 6.20÷7.00g/cm^3.

III. RESULTS AND DISCUSSION

The tensile strength was determined according to EN 10045-1, and the shape of the studied samples corresponds to the diagram in Fig.1.

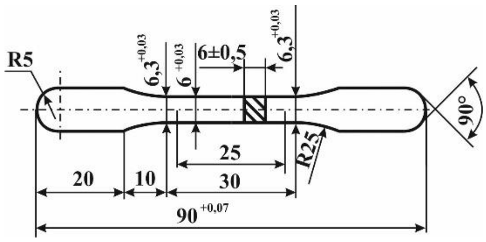

Fig.1.Drawing of a tube made of powder material for testing tensile strength

To eliminate the influence of porosity on the final results, three samples were used in the research, and the values in the figures are the arithmetic mean obtained for each type of sample [37].

For pure iron samples, the experimental results are presented in Fig. 2.

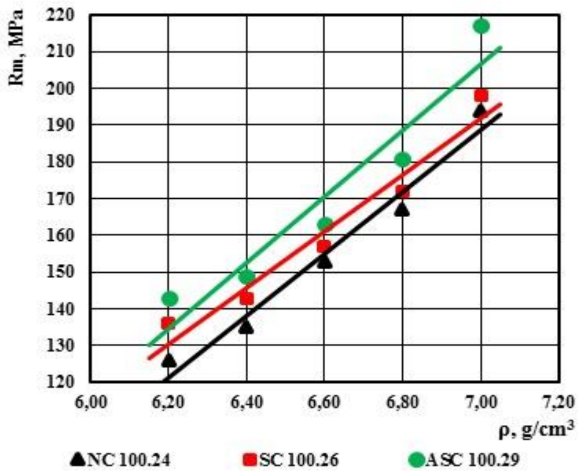

Fig.2. Tensile strength as a function of density of iron samples

The figure shows that with increasing density of the samples, the values of tensile strength also increase, as for samples of iron powders NC100.24 and SC 100.26 this increase is of the order of 60÷70MPa, and for those of ASC 100.29 - 70÷80MPa. In this case, the change in the values of tensile strength is only a consequence of the reduced porosity, the increased surface contact between the iron particles of the samples and their increased density. At all studied densities, the obtained results for the tensile strength for the samples of iron powder ASC 100.29 are higher on average by 20MPa compared to those obtained for samples of powders NC100.24 and SC 100.26. The fact that spherical powders have better compactability compared to spongy ones is confirmed. This allows the tensile strength of spherical iron particles to be higher by an average of 10% [38, 39, 40].

The addition of 0.2% carbon leads to an increase in the values of the tensile strength, and for the three types of iron matrices studied by us this increase varies in the range of 30÷60MPa and is a function of their density. - Fig. 3. The lower values are realized in samples with a lower density, and the higher ones in those with a density of 7.0g/cm^3. This can be explained by the fact that in denser samples the contact between the iron and carbon particles is increased, which facilitates the diffusion of carbon into the ferrite and the formation of a pearlite structure.

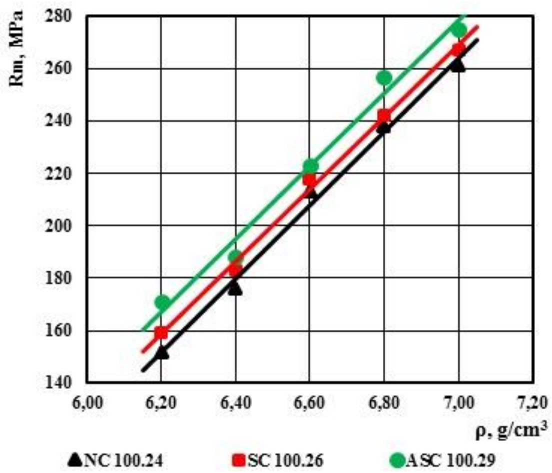

Fig.3. Tensile strength as a function of density of iron samples containing 0.2%C

With an increase in carbon concentration from 0.2 to 0.8%, the values for tensile strength increase in the range of 70÷120MPa, and similarly to the previous case, the larger increase of 110÷125MPa is observed in samples with lower porosity and correspondingly higher density – Fig. 3÷6.

The addition of 0.2% carbon leads to an increase in the values of the tensile strength, and for the three types of iron matrices studied by us this increase varies in the range of 30÷60MPa and is a function of their density. The lower values are achieved in samples with a lower density, and the higher ones in those with a density of 7.0g/cm^3. This can be explained by the fact that in denser samples the contact between the iron and carbon particles is increased, which facilitates the diffusion of carbon into the ferrite and the formation of a pearlite structure.

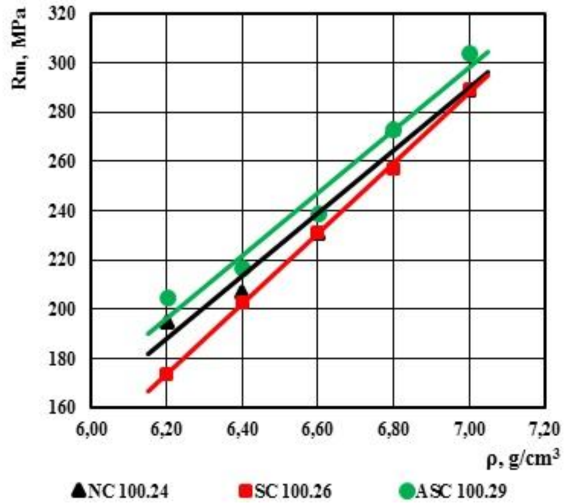

Fig.4. Tensile strength as a function of density of iron samples containing 0.4%C

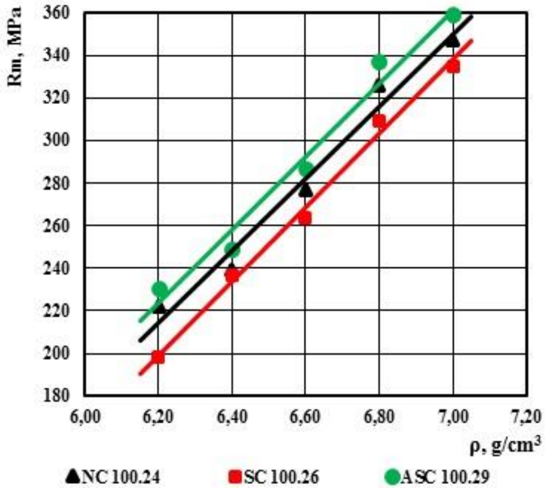

Fig.5. Tensile strength as a function of density of iron samples containing 0.6%C

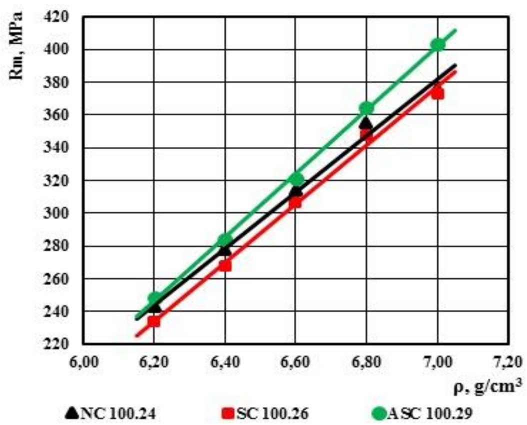

Fig.6. Tensile strength as a function of density of iron samples containing 0.8%C

The addition of 0.2% carbon leads to an increase in the values of the tensile strength, and for the three types of iron matrices studied by us this increase varies in the range of 30÷60MPa and is a function of their density. The lower values are achieved in samples with a lower density, and the higher ones in those with a density of 7.0g/cm^3. This can be explained by the fact that in denser samples the contact between the iron and carbon particles is increased, which facilitates the diffusion of carbon into the ferrite and the formation of a pearlite structure [33, 34, 36].

The highest values for tensile strength are recorded for samples alloyed with 2.5% copper. For parts containing 0.2% carbon, with an increase in density from 6.20 to 7.0g/cm^3, the values for tensile strength increase within the range of 200÷360MPa - Fig. 7, which is an increase of the order of 25÷30%. With an increase in carbon concentration from 0.2 to 0.8% - Fig. 7.÷10, the difference in the values for tensile strength also increases. For samples with 0.8%C, their strength varies in the range of 260÷560MPa - Fig. 10.

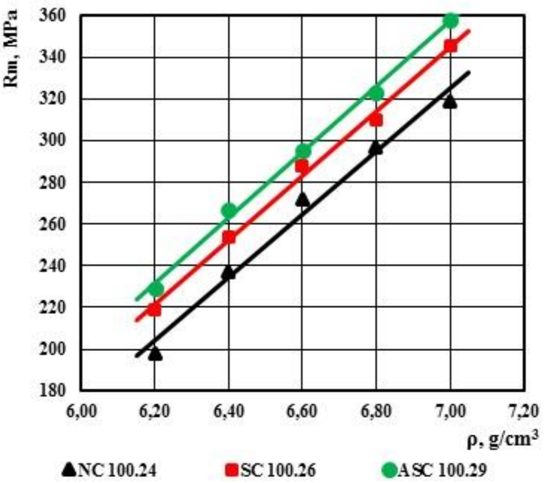

Fig.7. Tensile strength as a function of density of iron samples containing 0.2%C and 2.5%Cu

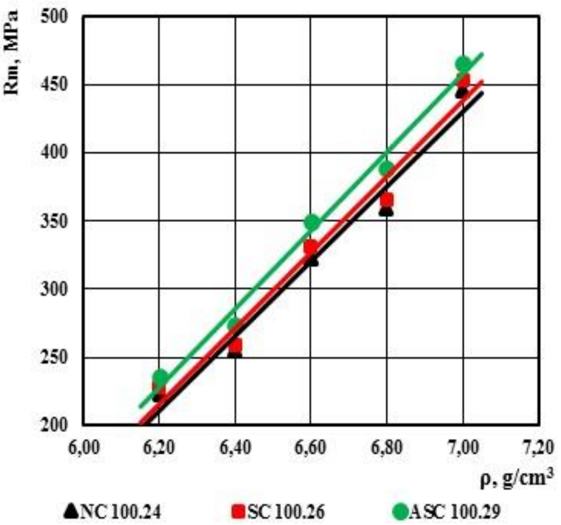

Fig.8. Tensile strength as a function of density of iron samples containing 0.4%C and 2.5%Cu

Similarly to the samples with a carbon content of 0.2%, in this case, the largest differences in the values are recorded for the samples with the maximum density studied by us - 7.0g/cm^3.

Comparing the results obtained for samples from the Fe-C and Fe-C-Cu systems, it can be concluded that the addition of 2.5% copper leads to an increase in the tensile strength by 50÷150MPa, with the largest differences being recorded for the samples with a higher density -7.0g/cm^3.

In the samples containing carbon, as well as in those alloyed with 2.5% copper, the influence of the brand of iron powder used on the tensile strength values is also noticeable. In the samples made of iron powder type NC 100.24 and SC 100.26, the measured tensile strength results are 10÷20MPa lower than those measured in samples with an iron matrix made of ASC 100.29 powder.

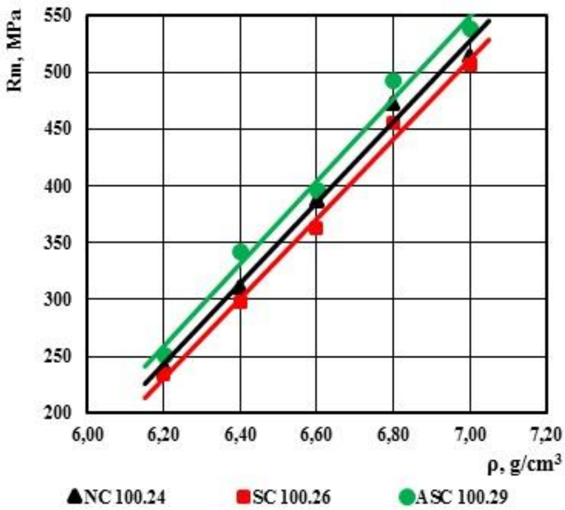

Fig.9. Tensile strength as a function of density of iron samples containing 0.6%C and 2.5%Cu

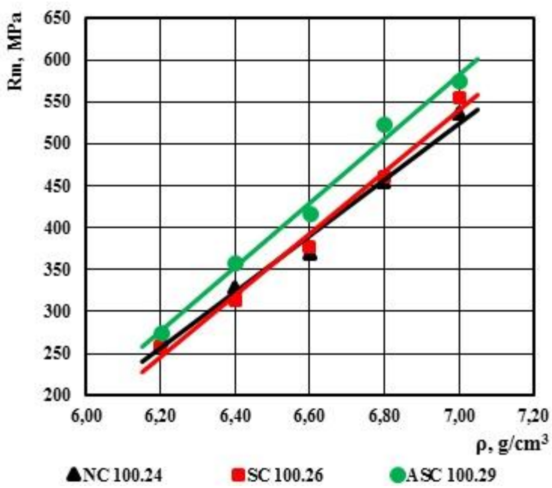

Fig.10. Tensile strength as a function of density of iron samples containing 0.8%C and 2.5%Cu

IV. Conclusions

From the conducted studies and the results obtained, the following important conclusions can be drawn:

- It has been confirmed that for samples of pure iron with an increase in their density from 6.20 to 7.0g/cm3, the values of the tensile strength increase by 60÷70MPa and do not depend on the type of iron powder used.
- It has been proven that adding 0.2% carbon to iron samples leads to an increase in tensile strength values by 30÷60MPa, which is a function of their density. Denser samples have higher strength due to increased particle contact and ongoing coalescence processes during sintering.
- It has been proven that the addition of 2.5% copper leads to an increase in the tensile strength values of iron-carbon materials by 50÷150MPa, with larger differences being observed for samples with a higher density -7.0g/cm3. In this case, the increased strength characteristics are a consequence of intensifying the sintering process of the samples in the presence of a liquid phase in the batch.
- It has been confirmed that the tensile strength measured for the samples of iron powder type NC 100.24 and SC 100.26 is 10÷20MPa lower than those measured for samples with iron matrix of ASC 100.29 powder. This is a result of the better compaction of the powders with spherical particle shape compared to those with spongy or dendrite shape.

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