STUDY OF STRUCTURAL AND SELECTED MECHANICAL/PHYSICAL PROPERTIES OF METAL POWDERS

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Abstract

Study of structural and mechanical physical properties of metal powders is important considering the processes in powder metallurgy. The procedural behavior of copper, iron and aluminum powders depends on many parameters. Therefore metal powders are most thoroughly characterized with size, shape and distribution of particles. In this research work the attention is paid not only to properties of individual particles, but also their collective, volume mechanical and physical quantities such as flowability, aeration of powders or compression. For the samples of copper, iron and aluminum powder has been determined particle size distribution, particles shape and surface topography of the sample using the EDF Z profile (extended depth of field) in connection with their mechanical and physical properties. The smooth, spherical aluminum particles show without one degree, the angle of internal friction so called "Ideal bulk material", unlike the iron powder with grains of rugged structure with internal friction angle of 43°. These way defined Fe particles with distinct ruggedness of surface show a low degree of compressibility or any other method of formation. In the field of aeration it is difficult fluidisable powder. This demonstrates not only the material classification into group B according to Geldart, but also the aeration test result itself. 3D microscopic evaluation of copper powder particles shape has been defined as micro leaf-shaped. The Cu sample corresponds with pronounced compressibility 4.6%.

Keywords: Metal powders, particle shape, angle of internal friction

1. INTRODUCTION

Metal powders are basic materials for powder metallurgy. Powder metallurgy is a progressive technology for the manufacture of structural and functional materials, and its benefits include a better use of the incoming materials and hence, production cost reduction. Metal powders find use in the manufacture of materials, e.g., for electrical engineering (magnetic materials, hard-melting metals, contact materials) [1], optoelectronics, catalysis [2] and biosensors [3].

A metal powder can be defined as a crystalline substance with a tight arrangement of the building units (high coordination number) and with typical physical properties which are frequently governed by the nature of the bonds between the atoms in the crystalline metal powders. The bonds between the atoms in the metal powder crystals have neither a directional nature nor multiplicity (multiple covalent bonds). The bonds in metal powders can be looked upon as an extreme case of a delocalized covalent bond, created by the overlap of the external orbitals in the atom with similar ones, surrounding it in the crystal structure [4].

Study of the properties of metal powders as the input materials is of importance in gaining insight into the basic principles of powder metallurgy. Generally, the properties of metal powders can be categorized into basic properties, such as particle size and shape, technological properties, such as bulk density and compressibility, and joint properties such as electrical conductivity and heat conductivity [1]. More or less straightforward relations exist between the basic, technological and joint properties. The aim of the present work was to disclose the relations between the structural and selected basic/technological properties of metal powders - specifically copper, iron and aluminium powders. Copper powder possesses a face-centered cubic crystal structure and exhibits outstanding electrical and thermal conductivity. It is also frequently used as an alloying element for iron powder components with a view to improving its mechanical properties [5]. Iron metal powder possesses a body-centered crystal lattice (α modification), whereas aluminium metal powder crystallizes in the face centered cubic system. Structural properties and mechanical/physical properties of powders are important especially for gaining a detailed idea for understanding material systems, which are subject to extensive research, especially in process engineering of powders and bulk materials.

2. EXPERIMENTS AND METHODS

2.1. Materials

The copper, iron and aluminium powders were purchased from Fichema. Their surface roughness was examined based on the EDF Z profile and 3D photographs taken on a Nikon AZ100 stereomicroscope. (Note: the EDF [extended depth of field] Z profile provides dependence of the powder surface's *z* axis at a given *x* position. The algorithm combines images of the planes into a single sharp composite approximating the metal powder's real topography [6, 7].)

2.2. Particle size distribution

Particle size distribution was determined by the wet method by using a CILAS 1190 laser analyzer, where coherent light 830 nm wavelength from a low-power laser diode passes through a cell containing the metal powder dispersed in water or in air and is scattered by that medium. The results were interpreted based on Fraunhofer's theory.

2.3. Bulk properties

The bulk properties of the powders were measured on an FT4 Powder Rheometer, which allows flow energy to be measured in relation to many variables and all packing states, shear properties of the consolidated or unconsolidated powders, bulk properties, compressibility and aeration.

Angle of internal friction

The rotary shear module for measuring friction parameters consists of a vessel containing the sample powder and a shear head to cause normal and shear stress. The blades of the shear head sink into the mass powder and the front face of the head starts to apply normal stress to the surface of the powder bed. The shear head moves downwards until sufficient and stable pressure is applied between the head and the powder bed. Then the shear head starts to rotate slowly and thus cause shear stress within the bulk mass. The shear plane is formed just below the end of the blades. Since the powder bed prevents rotation of the shear head, shear stress in the measuring plane increases until a slippage occurs. Then, the maximum value of transferred shear stress is recorded.

Compressibility

Compressibility is measured as the change in volume or density, respectively, depending on a normal load. The data obtained are quantified by expressing the percentage compressibility for a normal load of 15 kPa applied by the module, which is part of the FT4 Powder Rheometer.

Aeration

In the aeration test, air is fed to the bottom of the FT4 measuring cell and aerates the whole bulk material (sample) column. The dependence of the powder's flow properties on the amount of air is examined by measuring the decreasing flow energy.

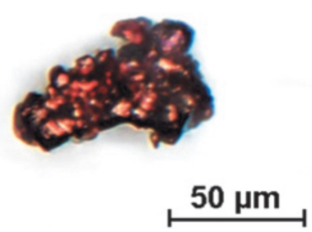
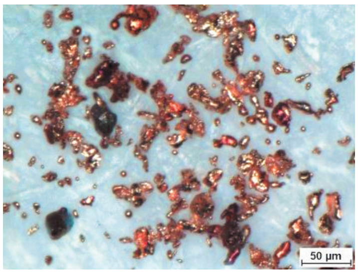
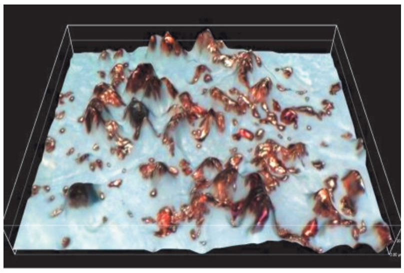
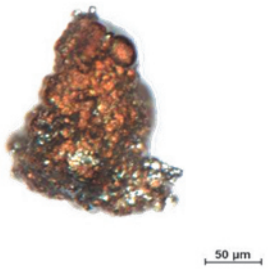
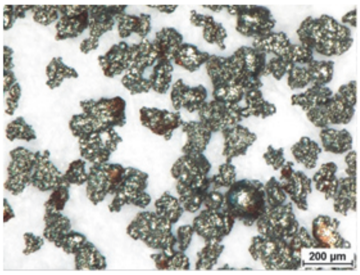
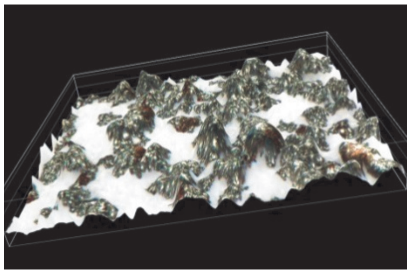
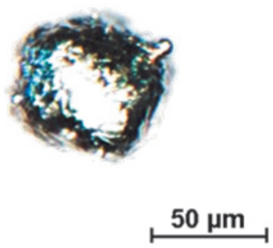
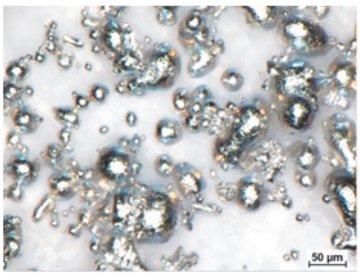
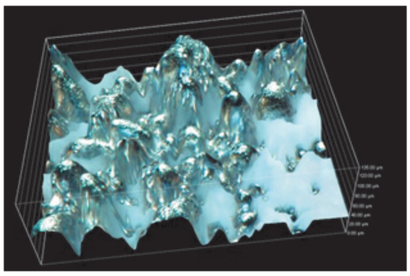
3. RESULTS AND DISCUSSION

Particle size distribution was determined by the laser diffraction method for all the metal powders investigated (**Table 1**). The largest particles were found in the iron powder, the smallest (34 µm in average), in the copper powder. However, this experimental method fails to provide information regarding surface roughness or surface structure. Therefore, a microscopic photograph (3D surface plot) was taken for each sample (**Table 2**), and the EDF Z profiles were generated (**Fig. 1**).

Table 1 Particle size distribution of copper, iron and aluminum powders

Parameter/Material	Cu	Fe	Al
d_{10}, [µm]	14.17	82.83	26.70
d_{50}, [µm]	34.38	134.05	69.72
d_{90}, [µm]	56.35	219.43	125.34

Table 2 Microscopic photos of copper, iron and aluminum particles and their 3D surface plot images

	Particle	Microscopic photo	3D surface plot image
Cu			
Fe			
Al			

The microscopic photographs demonstrate appreciable surface roughness particularly in the iron powder with leaf-shaped particles. The copper powder particle shape is described as micro-leaf-like, while aluminium powder consisted of smooth spherical drop-like particles (**Table 2**). Comparison of the conventional microscopic photographs and the 3D surface plots reveals a basic difference between the mutual positions of the powder particles and the particle-substrate position. While the microscopic photograph suggests a self-similar boundary, the 3D surface plots represent a self-affine profile. The self-affine profiles scale up in the vertical (*z*) direction (**Fig. 1**).

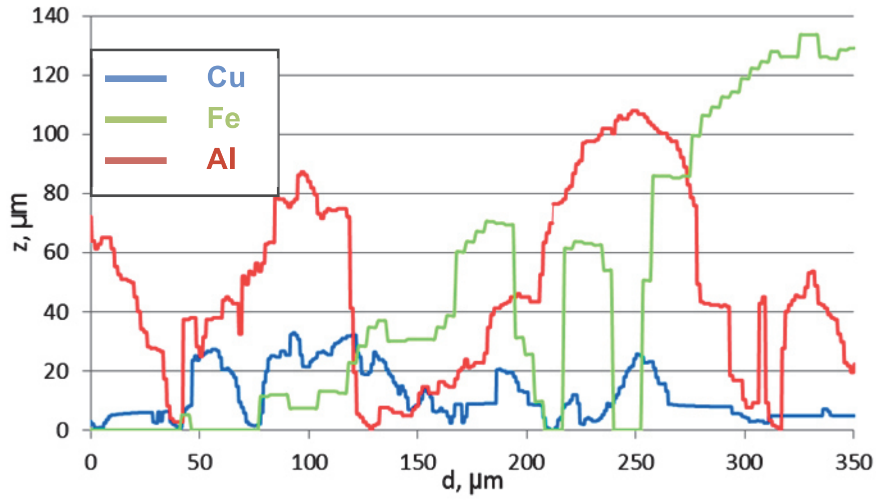


Fig. 1 Self-affine profiles (EDF Z profiles) which correspond with surfaces roughness parameters

The roughness amplitude descriptors as indicators providing basic descriptive informations were generated in order to enable the EDF Z profiles to be compared. They include the standard deviation (*Rd*) and maximum peak high (*Rp*), depending on the isolated particles. The descriptors are used for characterizing the surface roughness patterns, and can be applied as such also to metal powders [7].

Table 3 Selected surface roughness parameters - standard deviation (R_d), maximum height (R_p)

Parameter/Material	Cu	Fe	Al
R_d, [µm]	8.8	33.7	28.7
R_p, [µm]	32.9	130.8	107.9

Appreciable roughness of the iron powder was also confirmed by the calculated surface parameters, which are highest among the powders studied. Copper powder, although possessing appreciable surface roughness as well, exhibits the least pronounced fluctuation in the *z* direction away from the substrate.

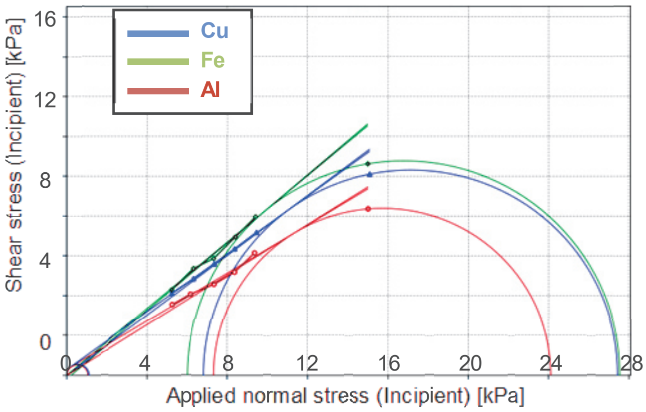


Fig. 2 Shear tests of metal powders

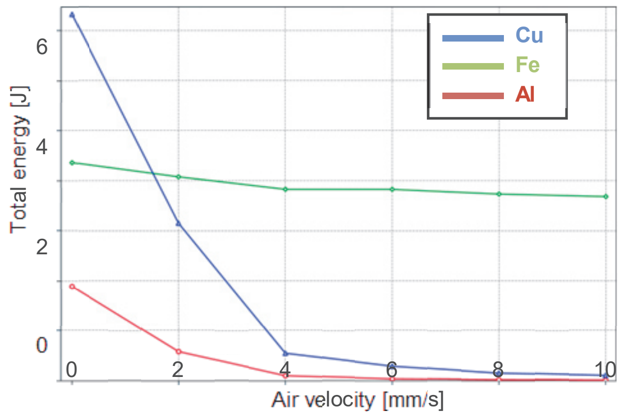


Fig. 3 Aeration tests of metal powders

The description of the sample surfaces based on the 3D surface plots and EDF Z profiles was correlated with selected mechanical/physical properties. Shear tests (**Fig. 2**), compressibility (**Table 4**), and aeration ratios (**Fig. 3**) were measured for all of the powders.

The angles of internal friction are seen to be markedly affected by the metal powder structure and particle size. The rather high value of 40.5° for iron powder (**Fig. 2**) attests to appreciable particle surface roughness associated with a large specific surface area. The smooth spherical particles provide an angle of internal friction of 31.2°.

Table 4 Flowability, compressibility and aeration tests results for copper, iron and aluminum powders

Material	Cu	Fe	Al
Cohesion [kPa]	0.279	-0.180	0.292
Unconfined Yield Strength [kPa]	1.09	n/a	1.03
Major Principle Stress [kPa]	27.4	27.6	24.1
Flow Function	25.1	n/a	23.3
Angle of internal friction [°]	36.0	40.5	31.2
Bulk Density [g/cm^3]	3.05	3.04	1.46
Compressibility at 10 kPa [%]	3.91	1.68	3.19
Compressibility at 15 kPa [%]	4.60	1.98	3.50
Basic Flowability Energy [mJ]	7318	4360	1893
Aeration Ratio (Air Flow Rate: 10 mm/s)	66.6	1.18	125

In powders, bulk property is influenced by many factors such as particle size distribution, cohesiveness, particles shape and particle surface texture. Compressibility test showed clear-cut differences. The largest particles, i.e. those of the iron powder, with the highest surface roughness parameters (see **Table 3**), exhibit the lowest compressibility (1.98 %) while the structured smallest particles of copper powder exhibit the highest compressibility (4.60 %).

The bulk properties of all the metal powders are also affected by air, since the void space between the particles is filled with air. The amount of air affects mutual particle interaction and hence, the powder flow properties. The measurements showed that from among the three metals, aluminium powder requires the lowest energy to form the fluidized bed, in contrast to the iron powder which is difficult to fluidize. In Geldart's categorization, copper and aluminium powders can be classed in group A (as well aerable materials), whereas iron powder, with its higher density and larger particles, falls in group B [8].

4. CONCLUSION

The present contribution illustrates existing relationships between structural properties and selected mechanical/physical properties of powders of three metals: copper, iron and aluminium. 3D surface topography on the microscopic scale appears to be a suitable tool for evaluating the basic structural properties of metal powders for scientific as well as industrial purposes. The selected mechanical/physical properties included angle of internal friction, compressibility and behaviour in aeration.

Aluminium powder particles were found to be spherical, nearly drop-like, whereas iron and copper powder particles exhibited appreciable surface roughness and were leaf-shaped or microleaf-shaped. The angle of internal friction of aluminium powder was fairly low, 31°, while copper and iron powders with their rougher particle surfaces exhibited higher angles of internal friction. In line with this, aluminium powder was the easiest to bring to the fluidized state (aeration energy 15.1 mJ). The compressibility parameter was most pronounced for copper powder, whose small particles are easiest to rearrange into tighter formations.

It can be deduced that the key parameters affecting the behaviour of the metal powders during the technological processes must be identified and determined in order to be able to optimize powder metallurgy processes. We demonstrated that the shape and surface structure (roughness) of the powder particles are among such parameters, capable of affecting the angle of internal friction, compressibility and fluidization behaviour.

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