EFFECT OF PARTICLE SHAPE AND SIZE ON THE COMPRESSIBILITY AND BULK PROPERTIES OF POWDERS IN POWDER METALLURGY

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Abstract

Study of structural and mechanical properties of metal powders is necessary for improving in powder metallurgy. The procedural behavior of aluminum, copper and iron powders and their alloys is important for many industrial applications. This paper presentshow the shape and size of the particles influence compressibility and flow properties of metal powders.These properties play an important role in the storage, handling, dosing and compaction in powder metallurgy processes. For the samples of aluminum, copper, iron and their mixtures has been determined particle size distribution and shape of particles thus posing its mechanical properties. The biggest irregular iron particles exhibit very low compressibility about 2% at 15 kPa applied normal stress. Conversely the fines copper particles are the most compressible. All of the basic powders indicate low compressibility at low normal load but different mixtures show bigger compression immediately after load application.

Keywords: Metal powders, powder metallurgy, compressibility, morphology

1. INTRODUCTION

Powder metallurgy (PM) 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. PM technology can be successfully applied to the manufacture of components from almost all common metallic materials. Also it allows produce components of very complex shapes often without the need for final machining which brings considerable savings in material and energy. In many cases the properties of the material produced technologies PM surpass adequate material produced by different technology, e.g. a hard steel for machining, certain aluminum alloys, friction materials, magnetic materials, etc. The powder metallurgy includes also the production and processing of non-metal powders like a copper, aluminum or titan into products whichexhibitmetallic properties, e.g., magnetic materialsbased on iron oxides. Powder metallurgy productsare mainly used inthe automotive industry, mechanical engineering, aerospace, medicine, the oilindustry, etc. The ability sintering combine alloys which are difficult or not at all be made using conventional metallurgy casting allows obtain almost any material or combined with new features. This characteristic is particularly useful for components with very different melting temperatures, limited mutual solubility in the liquid state and with very different densities [1]. Occasionally, powders are milled with a liquid medium during mechanical alloying and this is referred to as wet milling. Compared with dry milling, wet milling can avoid the aggregation effect of the powders and produce finer particles with higher powder yield. It is a popular and suitable method for producing the fine particles (even in nano-size) because of its simplicity and applicability [2].

Aluminum alloys occur in the automobile, machinery manufacturing, aerospace, and chemical industries, because they are resistant to abrasion and corrosion are lightweight, and have a high specific strength. Al-Cu alloys are one of the most important Al alloys and are widely used in the wheel bearings of airplanes and the screws of ships. Al-Cu alloys coat the surfaces of microelectronic devices and high-current-density devices as oxidation barriers [3].The Fe-Cu bimetallic alloy system is attractive for many applications due to its high strength, and high-electro/thermal conductivity. Similar to other metastable alloy systems, e.g. Ni-Ag, Cu-V and Co-Cu, they suffer from the main drawback of being immiscible assolid solutionsdue to their positive energy of mixing. Thus they will not form intermetallic compounds and will havenegligible mutual solidsolubility in equilibrium at temperatures below 700 °C. One effective and easy method to synthesize the Cu-Fe system without high energyin the form of applied heat or voltage is mechanical alloying, which has the advantages of low-temperature processing, easy control of compositions, and the production of relatively large amount of samples [4].

Study 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 attributes, such as particle size and shape, technological features, or bulk density and compressibility [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, aluminum powders, and their mixtures [5].

2. EXPERIMENTS AND METHODS

2.1. Materials

Three types of powders and three types of their alloys ($Al_{50}Cu_{50}$, $Al_{50}Fe_{50}$, $Cu_{50}Fe_{50}$, in weight percent) were prepared from Fe (min. 99% purity), Cu(99.7% purity) and Al. Commercial metal powders (Fichema s.r.o., Brno, Czech Republic) were bought for the experiment. 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 [6]. Iron metal powder possesses a body-centered crystal lattice (α modification), whereas aluminum metal powder crystallizes in the face centered cubic system. Structural 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 [5]. Micro-mill Fritsch Analysette 3 Spartan was used for preparing the mixtures of powders. Each of the sample was blended for 40 minutes.Following six samples were tested to particle size distribution, particle shape, compressibility, angle of internal friction and bulk density.

2.2. Particle shape and size distribution

Particle size distribution was tested by using a CILAS 1190 laser analyzer (wet method), with coherent light 830 nm wavelength from a low-power laser diode passes through a cell containing the metal powder dispersed in water like carrying medium. The results were interpreted based on Fraunhöfer's theory. The Fraunhöfer theory was used due to particles that are not so fine (bigger than 1 μm) and transparent. Determination of the particle shape was based on SEM photos and microscopic photos captured by microscopic equipment of stereomicroscope Nikon AZ100 within particle size distribution measurement by CILAS 1190.

2.3. Powders properties

The bulk properties of the powders and mixtures were measured by Freeman Technology FT4 Powder Rheometer.The FT4 Powder Rheometer is a universal powder tester - three instruments in one, combining patented blade methodology for measuring flow energy with a range of shear cells, wall friction modules and other accessories for measuring bulk properties.This means quantifying the effects of consolidation, vibration, segregation, moisture uptake, fines, aeration, flow rate, air entrainment and a number of other factors. Such characterization using complementary methodologies has wide application in the formulation, processing and QC sectors of most powder processing industries [7].

Angle of Internal Friction (Shear Cell)

Shear properties are important for understanding how easily a previously at rest, consolidated powder will begin to flow.In every process and storage environment, powders will be subjected to consolidation stresses, causing changes in density and mechanical interparticle forces. For flow to occur, it is necessary that yield point of the powder is overcome.Physical properties such as size, shape and surface characteristics of the particles will greatly influence the yield point, as will variables like moisture content or level of flow additive.Whether it is transport in keg, storage in a hopper or processing through an IBC on the top of tablet press or roller-compactor, powders will be subjected to some level of consolidation stress during their handling.Measuring the shear properties will provide important information as to whether the powder will flow through the process or whether bridging, blockages and stoppages are likely [8].

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.Shear cell test gives a useful information about flow properties of powders which is important for design storage and manipulation equipment not only in powder metallurgy.

Compressibility

Compressibility is a measure of how density changes as a function of applied normal stress. For powders, this bulk property is influenced by many factors such as particle size distribution, cohesivity, particle stiffness, particle shape and particle surface texture. It is not directly a measurement of flowability, but nevertheless relates to many process environments, such as storage in hoppers or super sacks, or behavior during roller compaction, for example. Generally, cohesive powders consisting of mainly sub 30 micron particle size are the most compressible, with powders of a granular nature being least compressible. Of course there are exceptions to this generalization and powders consisting of large but very elastic particles may also become readily compressed. Standard test of FT4 Powder Rheometer was done and the data obtained are quantified by expressing the percentage compressibility for a normal load of 15 kPa applied by the module. This test was used for comparison of different samples. Compressibility results are important for compaction process in powder metallurgy [7].

Bulk density and porosity

Bulk density is dependent on many physical properties, such as true density, particle size and distribution, particle shape, particle surface texture and cohesive/adhesive forces, to name just a few.In addition, external variables such as level of consolidation stress or vibration can readily change the air content in the powder bulk and this can result from movement or loading of the material, or just as a function of time if left at rest [8]. Bulk density was specified within shear cell test by Freeman FT4 Powder Rheometer. Also porosity of initial state of material was determined using the formula (1). Porosity ε expresses percentage difference between true and bulk density of granular material.

$$\varepsilon = 1 - \frac{\rho_{bulk}}{\rho_{true}} \qquad (1)$$

3. RESULTS AND DISCUSSION

Particle size distribution was determined by the laser diffraction method for three basic metal powders investigated (**Figure 1**). Samples have been properly chosen to investigate the influence of particles to compressibility.

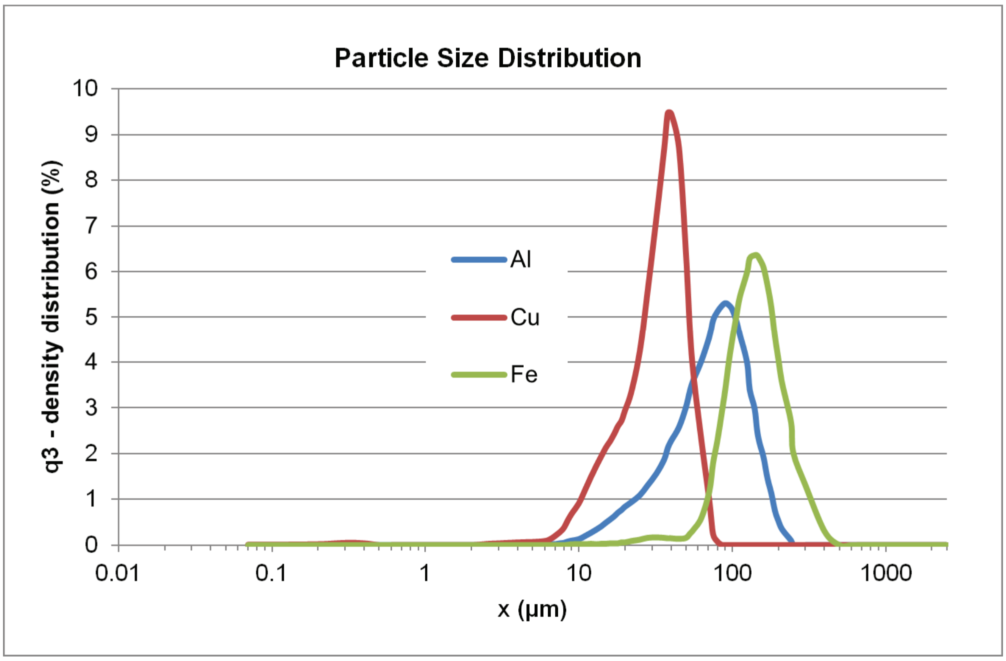
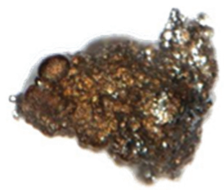
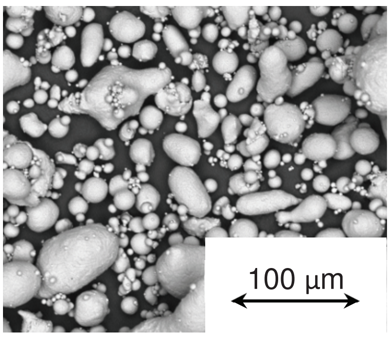
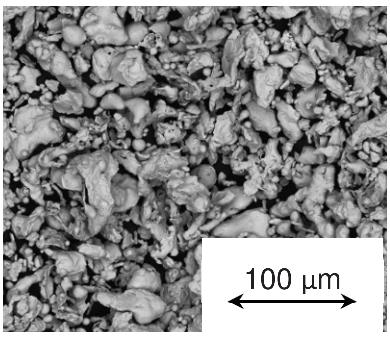
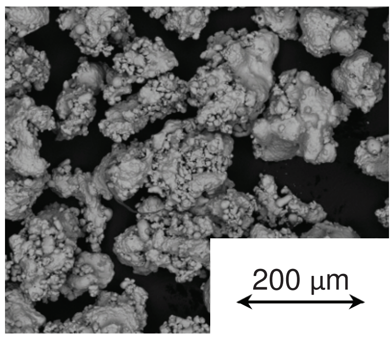


Figure 1 Particle size distribution of aluminum, copper and iron powder

Table 1 Microscopic and SEM photos of aluminum, copper and iron particles

	Al	Cu	Fe
Microscopic	 70 µm	 50 µm	 150 µm
SEM	 100 µm	 100 µm	 200 µm

The microscopic photos show iron porous powder with particles having rugged surfaces. The copper powder particle shape is described as micro-leaf-like, while aluminum powder consisted of smooth spherical drop-like particles (**Table 1**). We can use equation (1) to predict powders compressibility by porosity ε calculation when the bulk and true densities are known [9]. Round particles of aluminum show lower porosity (46%) than irregular particles of copper and iron that have values of porosity over 60% [10] **Table 2** shows how we can compare the two samples of the same particle size with different shape (Al-Cu) and conversely two samples with the same shape but different sizes (Cu-Fe).

Figure 2 describes compressibility of powders with different particles. Particle size distribution and shape are properties that affect the compressibility of powders [11]. The biggest irregular iron particles exhibitvery low compressibility about 2% at 15kPa applied normal stress. Conversely the fines copper particles are the most compressible. All of the basic powders indicate low compressibility at low normal load but different mixtures show bigger compression immediately after load application. Fe-X mixtures are less sensitive to compressibility than Fe powder thanks to fine particles addition. So we can state main effect of particle size on powders compressibility.

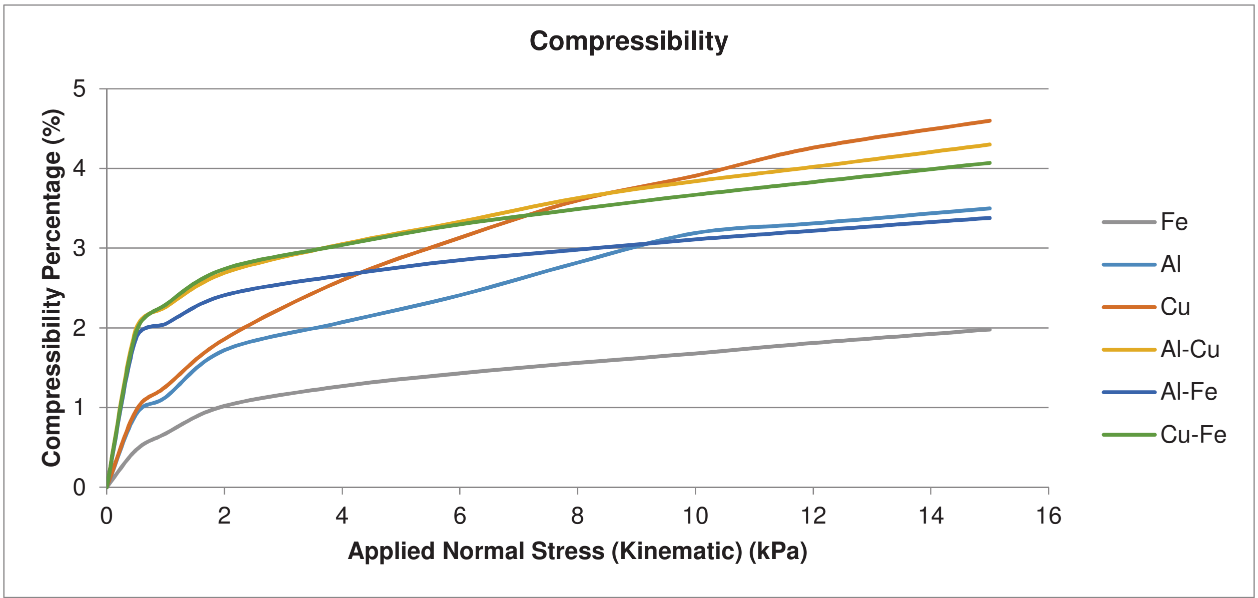


Figure 2 Compressibility of aluminum, copper, iron powders and their mixtures

Table 2 Properties and tests results for aluminum, copper, iron powders and their mixtures

Sample	Al	Cu	Fe	$Al_{50}Cu_{50}$	$Al_{50}Fe_{50}$	$Cu_{50}Fe_{50}$
Mean diameter: x_{10} (μm)	27.27	14.06	79.29	---	---	---
Mean diameter: x_{50} (μm)	72.53	33.18	134.05	---	---	---
Mean diameter: x_{90}(μm)	132.47	53.39	221.28	---	---	---
Mean diameter (μm)	77.06	33.69	143.07	---	---	---
Flow function (-)	23.3	25.1	18.7	16.1	28.6	32.5
Angle of internal friction (°)	31.2	36.0	37.6	31.5	36.4	36.4
Bulk density (g/cm^3)	1.46	3.05	3.03	2.16	2.85	4.14
Conditioned bulk density (g/cm^3)	1.44	3.15	2.92	2.44	2.14	3.55
True density (g/cm^3)	2.70	8.96	7.87	---	---	---
Initial porosity (-)	0.46	0.61	0.66	---	---	---
Compressibility at 0.5kPa (%)	0.92	0.96	0.47	1.99	1.87	1.95
Compressibility at 15 kPa (%)	3.50	4.60	1.98	4.30	3.38	4.07

The bulk properties of all the metal powders are also affected by air. Firstly, the oxidation film affecting flowability of metal powders can be formed. Secondly, the void space between the particles is filled with air volume. The amount of air affects mutual particle interaction and hence, the powder flow properties. AIF and flow properties are influenced by particle shape how we can see in **Table 2**. Round aluminum particles exhibit better flow properties even in mixtures. In combination with the similarly particle sized copper powder can improve flow properties of copper powder but cause just a little improvement of bigger sized iron powder. Also rounded particles addition cause an improvement of flow properties.

4. CONCLUSION

The generally accepted facts have been demonstrated in this study, that the compressibility is primarily influenced the particle size, while the flow properties depend on particle shape. Compressibility of the Fe powder was significantly increased by the addition of finer aluminum and copper powders. In case of Cu addition ($Cu_{50}Fe_{50}$) is compressibility four times higher at low normal loads. An influence of fine particles is suppressed when the normal load increases. Additives had significance for the copper powder compression only up to normal load at 8 kPa and all of the basic samples of metal powders are less sensitive to compressibility than their mixtures at low normal load. Round shaped metal particles exhibit better flow properties and lower porosity than irregular particles. The flow properties of Fe rugged particles were improved by fine Cu and Al particles addition.

ACKNOWLEDGEMENTS

This paper was conducted within the framework of the project LO1404: Sustainable development of ENET Centre and also within Student Grant Competition titled Process study of pneumatic conveying system SP2016/159.

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