CHARACTERISTICS OF THE MECHANICAL AND PHYSICAL PROPERTIES OF METAL POWDERS USED FOR HIGH SPEED SPRAYING OF MACHINE PARTS

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Abstract

In the field of powder metallurgy, the characteristics of metal powders are necessary for designing technological processes within transport, handling and storage. This paper is focused on the study of three metal powders, CrCNiCr, NiCrBSi, WCCoCr, which are used for the HVOF (High Velocity Oxy-Fuel) technology of high-speed thermal spraying. This technology is used by the company SERVIS ARMATUR in their own production programme. The company SERVIS ARMATUR cooperates with the Bulk Solid Centre, VSB - Technical University of Ostrava, in the field of metal powders characterization. Each of the three samples was subjected to detailed analysis. The analysis included a measurement of mechanical and physical properties such as particle shape, particle size distribution, the angle of internal friction, compressibility and aeration. Some recommendations for production were determined based on the results of physical-mechanical tests. Improvement was achieved primarily in storage, handling and dosage to the diffuser.

Keywords: Metal powders, powder metallurgy, mechanical and physical properties

1. INTRODUCTION

Metal powders are typical materials for technologies used in powder metallurgy in various forms. The basic advantages of powder metallurgy include a wide range of applications in the production of new metal materials or in the development of new powder mixtures for the surface treatment of machine parts [1]. Most industrial enterprises are forced to constantly reduce the production costs of their products due to an expanding competitive environment. One of the possible austerity measures in the field of powder metallurgy, namely in the manufacture of metallic machine parts, is through application of surface treatment of functional surfaces occurring on the manufactured metal components. Areas of manufactured parts which are not subject to wear or increased stress in their use may be made of lower grade materials. In this way, the production costs of the final products can be reduced. One of the most advanced technologies in surface treatment in the form of hot coating is the HVOF (High Velocity Oxy-Fuel) method. This technology is used by the company SERVIS ARMATUR [2] in their own production programme. HVOF technology uses a mixture of oxygen and kerosene as a source of thermal energy. Oxygen and kerosene are axially impregnated into the combustion chamber where atomization and the sparking of spark plugs occur. Combustion products are then accelerated in a convergent divergence nozzle up to supersonic values(Mach 1-2). The combustion chamber's pressure is monitored to ensure stable burning conditions and process reproducibility. With the aid of the nitrogen carrier gas, the metal powdered material is fed radially from opposite sides into the so-called diffuser, where it melts and, via the nozzle, it is accelerated significantly towards the coated part. The thickness of the coating generally ranges from 0.2 to 1 mm. A more detailed description of the technology can be found in the professional literature, e.g. [2,3,4]. The basic principle of HVOF technology and its practical application is shown in (**Figure 1**), which shows: 1-Inlet of metal powder to the diffuser, 2-Kerosene inlet, 3-Oxygen inlet, 4-Spray coating, 5-Base material (machine component), and 6-Spark plug.

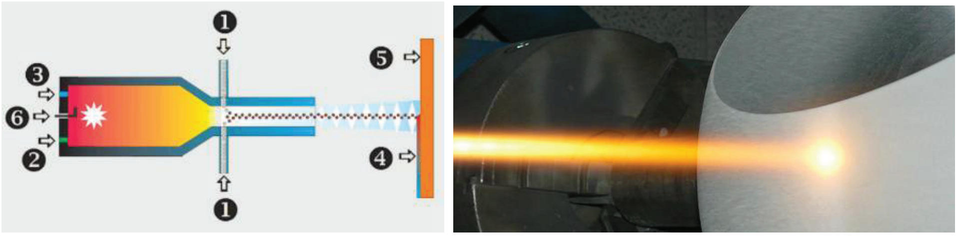


Figure 1 Basic principle of HVOF technology and its practical application [2]

The company SERVIS ARMATUR cooperates with the Bulk Solid Centre, VSB - Technical University of Ostrava, in the field of metal powders characterization. This paper is focused on the characteristics of three metal powders, CrCNiCr, NiCrBSi, WCCoCr, which are used for high-speed thermal spraying HVOF (High Velocity Oxy-Fuel) technology. As already mentioned, metallic powders are conveyed from the local reservoir to the diffuser by the nitrogen carrier gas. In the diffuser, they are subsequently melted and applied to the machine parts. The mechanical and physical properties of metal powders are especially important for understanding the material systems, which are the subject of extensive research, especially in the process of engineering powders and loose materials. Each of the three samples has specific mechanical and physical properties that affect their storage processes and transport to the diffuser itself. Based on a detailed analysis of each metal powder, it is possible to systematically change and adjust the ideal transport and storage systems for a given application [5, 6].

2. EXPERIMENTS AND METHODS

a. Materials

CrCNiCr metallic powder coatings are used in corrosive environments with high temperatures and the effects of abrasive wear; for example, valve stems, ball valves, hydraulic piston rods, furnace cylinders, as well as a general replacement for chrome plating. The second NiCrBSi metallic powder is used in cavitational and erosive environments; for example, pumps, piston rods, piston rings, forging industry, plungers, etc. The third material to be analysed is WCCoCr, which resists sliding, erosive, abrasive and adhesive wear; for example, slide valves, ball valves, hydraulic cylinders, compressor shafts, etc. The analysis included a measurement of mechanical and physical properties, such as particle shape, particle size distribution, the angle of internal friction, compressibility and aeration.

<u>Particle size distribution</u>

Particle size distribution of the individual samples was measured with the laser analyser CILAS 1190, where coherent light 830 nm wavelengths from a low-power laser diode passed 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.

<u>Angle of internal friction</u>

The angle of internal friction of the individual powders was measured on a FT4 pulse rheometer which allows the measuring of energy flow in relation to many variable consolidated shear properties or unconsolidated powders, bulk properties, compressibility, and aeration. The rotary shear modulus for measuring friction parameters consists of a container containing sample powder and a shear head, which causes normal and shear stresses. The shear head blades are dipped into the powder and the front of the head begins to exert a normal strain on the surface of the powder bed. The shear head moves downwards until there is a sufficient and stable pressure between the head and the powder layer. Subsequently, the shear head begins to slowly rotate and thus causes shear stress inside the bulk mass. The cutting plane is formed just beneath the blade edge. Since the powder bed prevents the shear head from rotating, the shear stress in the measuring plane increases until a slip occurs. Then, the maximum value of the transmitted shear stress [7] is recorded [7].

Compressibility

Compressibility is a measure of how density varies as a function of applied normal stress. For powders, this bulk property is influenced by many factors, such as particle size distribution, cohesiveness, particle stiffness, particle shape, and particle surface structure. It is not a measurement of fluid flow, yet it relates to many process environments such as storage in containers or behaviour during cylinder compaction. In general, cohesive powders consisting of a particle size of less than 30 microns are most compressible, while granulated powders are least compressible. Compressibility results are important for compaction in powder metallurgy [8].

Aeration

In the aeration test, air is fed to the bottom of the FT4 measuring cell and it 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. The aeration result is characterized by the Aeration Ratio, which is given by **Equation 1** [7, 9].

$$Aeration\ Ratio = \frac{FlowEnergy\left(Air\ velocity\_0\right)}{FlowEnergy\left(Air\ velocity\_N\right)}\ \frac{[mJ]}{[mJ]} = [-] \qquad (1)$$

3. RESULTS AND DISCUSSION

Particle size distribution was determined by the laser diffraction method for the three metal powders examined: CrCNiCr, NiCrBSi, and WCCoCr, see (**Figure 2**). Particle size distribution results show that the individual metallic powders range from 10 μm to 100 μm in the medium-fine range. For samples of CrCNiCr and WCCoCr, the average particle size is about 35 μm. The average particle size of the NiCrBSi sample is around 54 μm.

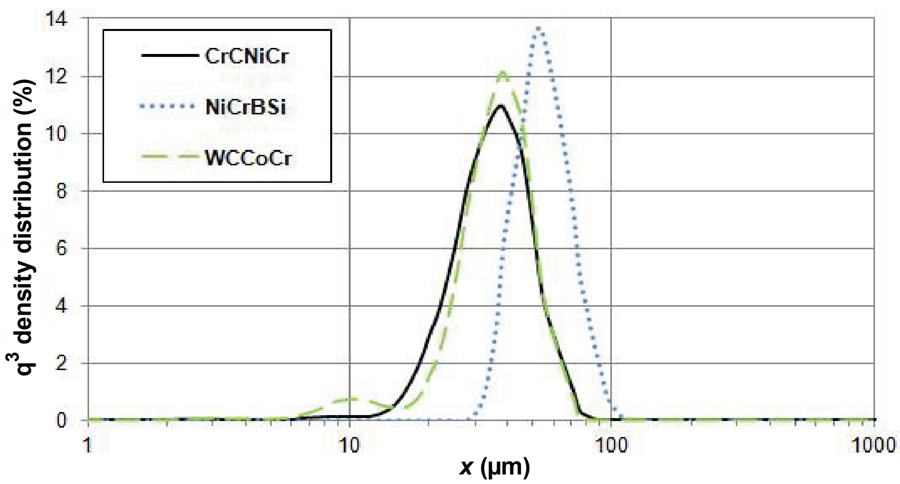


Figure 2 Particle size distribution of CrCNiCr, NiCrBSi, and WCCoCr powders

Figure 3 shows SEM photographs of individual samples showing the unique shape of the individual particles contained in the mixture. The NiCrBSi sample particles are of a shape most like the ideal sphere. The SEM photographs also show the heterogeneous porosity of the particle surfaces. The surface area of the CrCNiCr and WCCoCr samples shows relatively high porosity. In contrast, the NiCrBSi sample surface shows an almost smooth surface structure.

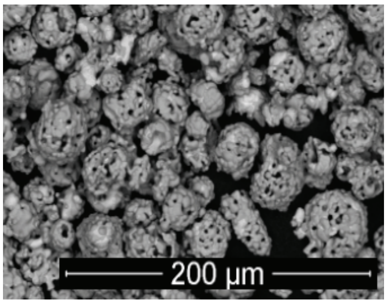
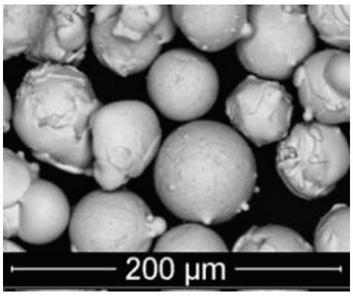
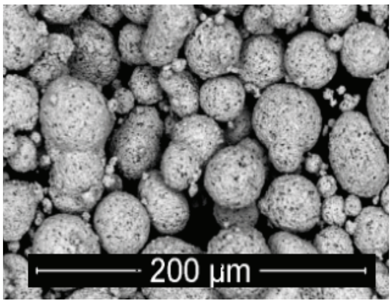
	CrCNiCr	NiCrBSi	WCCoCr
SEM			

Figure 3 SEM images of CrCNiCr, NiCrBSi, WCCoCr powder particles

Within the angle of internal friction measurement, the effective values of this quantity were determined. The angle of internal friction is greatly influenced by the surface porosity of the metal powder particles. A higher value of the angle of internal friction of 31.7° was obtained for the CrCNiCr sample. For the NiCrBSi sample, the angle of 23.1° was measured, and for the WCCoCr sample the angle of 24.6°. In the measured values of the internal friction angle, the varied surface porosity of the individual samples is evident, as can be seen from **Figure 3**. **Figure 4** shows the waveform of the normal and shear stresses, on which the resulting values of the effective angles of internal friction are based.

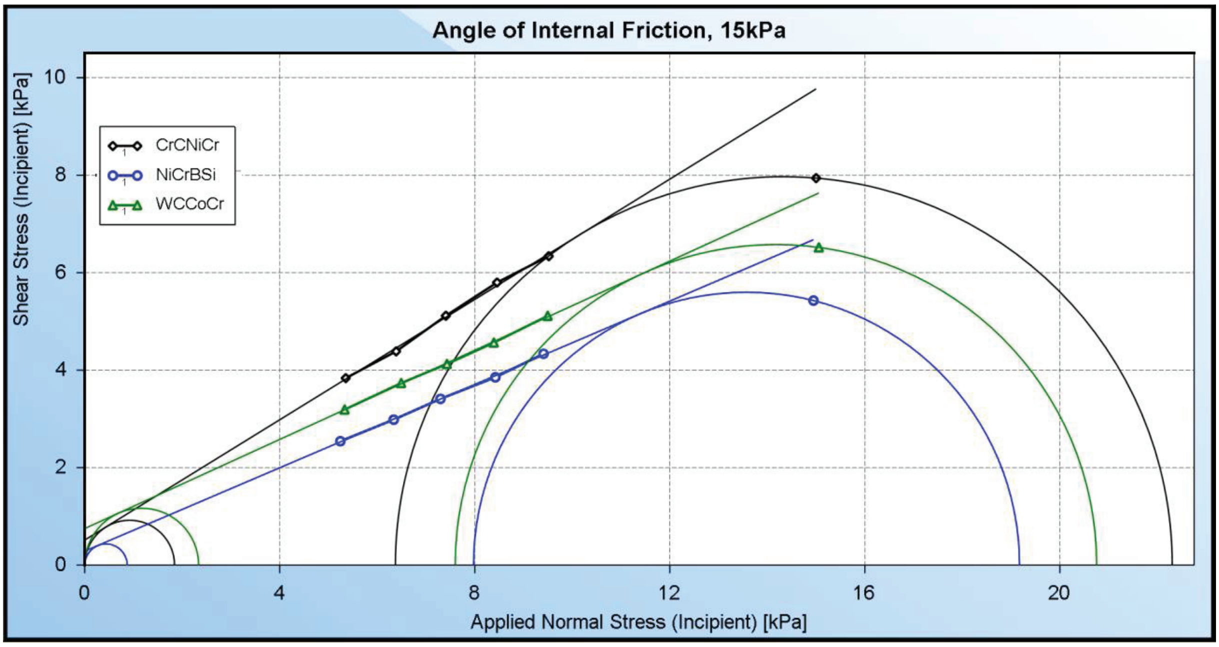


Figure 4 Angle of internal friction comparison at 15 kPa

Particle size distribution, cohesiveness, stiffness, particle shape and particle surface structure are dominant properties that affect the compressibility of powders [10]. Compressibility at 15 kPa maximum stress was almost identical for the CrCNiCr and NiCrBSi samples, approximately 3.8 %. The WCCoCr sample showed higher compressibility, almost 5 %. In general, all of these metallic powders exhibit low compressibility at low normal stress. The compressibility waveform for the individual samples in relation to normal stress is shown in **Figure 5**.

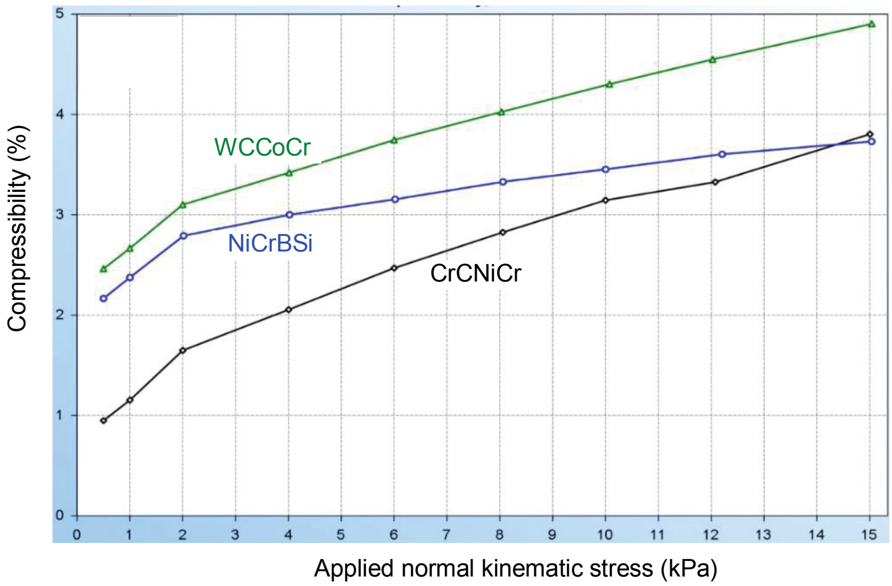


Figure 5 Compressibility 0.5 - 15 kPa of CrCNiCr, NiCrBSi, and WCCoCr powders

Figure 6 shows the patterns of the aeration test on the individual samples at different rates entering the air into the measured space. The measured Aeration Ratio (AR) for the CrCNiCr sample at 10 mm/s at the air flow rate was 80.5, for NiCrBSi it was 67.9, and for WCCoCr 60.9. All of these measured values fall into the category of powder materials that are very sensitive to aeration and can easily be brought into fluid form.

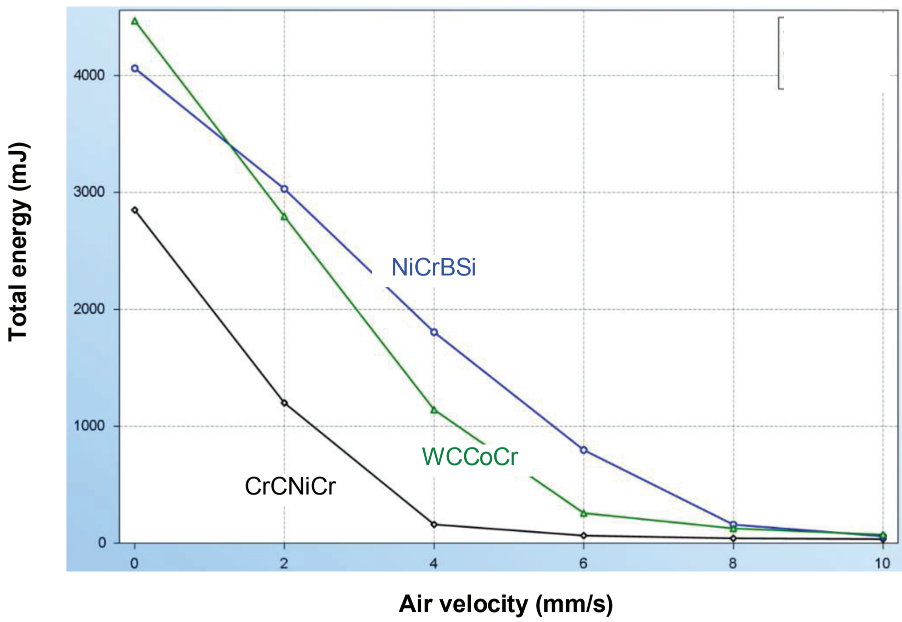


Figure 6 Aeration test at 0 - 10 mm/s of CrCNiCr, NiCrBSi, and WCCoCr

All measured mechanical and physical properties of the metallic powders are summarized in **Table 1**.

Table 1 Summarized results of the properties of CrCNiCr, NiCrBSi, WCCoCr powders

Sample	CrCNiCr	NiCrBSi	WCCoCr
x_{10} (µm)	21.13	38.29	21.14
x_{50} (µm)	33.59	51.60	34.45
x_{90} (µm)	49.94	72.20	49.54
Mean diameter (µm)	34.71	53.64	34.70
Angle of internal friction (°)	31.7	23.1	24.6
Compressibility at 15 kPa (%)	3.80	3.73	4.90
Aeration ratio (Air flow rate: 10 mm/s)	80.5	67.9	60.9

4. CONCLUSION

The measured mechanical and physical properties of the three metallic powders express the detailed information needed for the optimal design of storage and handling technology. Within the measured experiments, different surface porosity of the particles, which influences the discharge processes from the storage devices, was found in the individual samples. The surface area of the CrCNiCr and WCCoCr samples showed relatively high compression. In contrast, the NiCrBSi sample's surface shows an almost smooth surface structure. The CrCNiCr sample, with probably the highest surface porosity, exhibited the highest value with an angle of internal friction of 31.7°. The magnitude of the angle of internal friction affects the amount of loss of work when transporting and manipulating metal powders. The particle size for all samples was measured in the range of 10 µm to 100 µm. All metal powders exhibit relatively low compressibility. Surprising results were found in the aeration test, in which the aeration ration was measured well above the value of materials with high sensitivity to aeration. These materials can very easily enter the fluid state. This result shows it can be advantageous to use gaseous media when designing or optimizing transport and storage devices for the studied metal powders. In conclusion, the characteristics of metal powder parameters are very important for the design and optimization of technological processes in the field of powder metallurgy.

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