Manufacturing of powders by the method of metal spraying from the liquid phase

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Abstract: *Object of interest in the article is the method of metal spraying from the liquid phase (gas atomization method). Process involves melting of metal alloy and its subsequent spraying with the stream of inert gas. The quality of obtained powders depends largely on the properly conducted spraying, which results in powders properties – such as volume distribution and size of particles. Therefore, gas atomization method and relevant powders properties are reviewed. Experimental part covered investigations of alloy of tin, antimony and copper from the point of view of their volume fractions and chemical composition. It was concluded that method of metal spraying from the liquid phase enables ease control of grains geometry and assure high quality of manufactured powders.*

Keywords: *gas atomization, metal spraying, powders manufacturing, powders properties*

1. Introduction

Powder metallurgy is used in many welding technologies – including spraying, flame-, plasma-, gas- and laser welding, soldering, manufacturing of a bushing bearings. Object made by those technologies are made from powders of metals and their alloys without their melting and have favourable mechanical and wear properties. Object of interest of this paper will be the first step of powder metallurgy – powders preparation [1],[2].

There are dozens of methods of powders manufacturing. In the article, the method of metal spraying from the liquid phase (known also as gas atomization technique) is considered. Spraying involves breaking into droplets or streams of molten metal or locally melt metal, with the usage of compressed gases or liquids, mechanical forces or ultrasounds. This method produces powders of iron, steel, aluminium, zinc alloy, tin and lead [3].

Firstly, the theoretical review will cover the technology of metal spraying and suitable powders properties. Next, in the experimental part, the investigations of an alloy of tin, antimony and copper will be presented. Such powders are used amongst others for welding of bushing bearings. The volume fractions of sprayed particles, depending on their size, will be investigated. Subsequently, taken into account will be the role of chemical composition of the sprayed powders – the volume fractions of different metals and alloys will be compared, based both on the literature and authors' results.

Although the investigated spraying method is known since 1882 (first sprayed material was lead) [4], in Poland powders manufacturers are missed. Nevertheless, the validity of presented study confirms gradual development, undertaken by Department of Welding at Mechanical Department of Wrocław University of Technology. Since 2007 exist there an university laboratory which manufactures metallic materials for welding purpose [1]. The quality of manufactured powders determines many properties – for example, mechanical properties of coatings in the spraying processes. It subsequently decides about the product durability and safety of users. Therefore, the development of gas atomization method seems to be an important issue in polish powders industry.

2. Materials, technologies and methodology

The method of metal spraying from the liquid phase is conducted using the station for powders manufacturing (Fig. 1). The process of production metal powders consists of pouring molten metal *1* to the spray nozzle *3* and is subsequently followed by powder spraying with compressed nitrogen, argon or other inner gas stream a spray tower *2* (spraying chamber dimensions: height - 5 m, diameter – 2 m). Then, the gas is cleaned of residual powder by de-dusting equipment: cyclone *4* and filter *5*. The gas flowing out the nozzle has high speed, often even supersonic [1], [6].

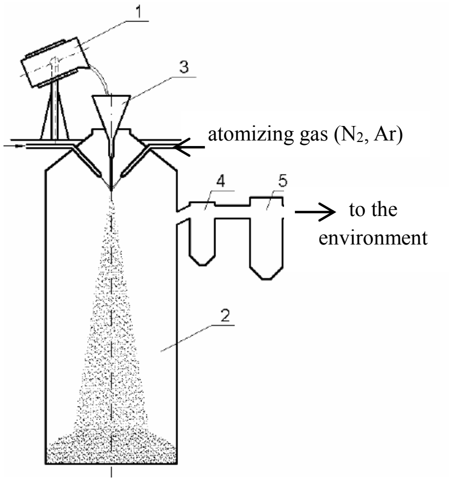

Fig. 1 Scheme of station for spraying metal by gas from the liquid phase. *1* – liquid metal, *2* – spray tower, *3* – spray nozzle, *4* – cyclone, *5* – filter with replaceable cartridges [1].

The manufacturing of powders of tin, antimony and copper was conducted in laboratory built by Department of Welding at Mechanical Department of Wrocław University of Technology. The station (own construction) was used for the for the preparation of metal powders, sprayed from the liquid phase (Fig. 2).

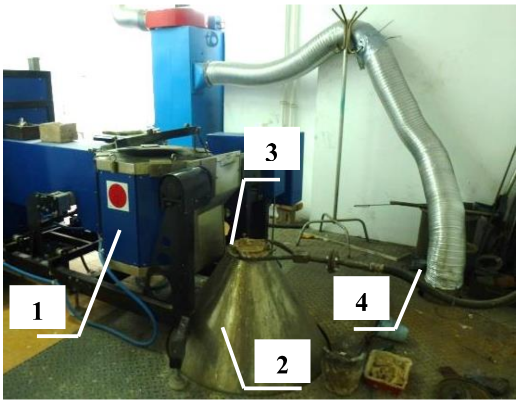

Fig. 2 Station for metal powders manufacturing by gas atomization method. *1*- melting pot, *2* – spray tower, *3* – spray nozzle, *4* – ventilator.

Inert gases used during the tests was nitrogen. The feedstock (Fig. 3) was an alloy of tin, antimony and copper with the following chemical composition: 89% Sn + 7,5% Sb + 3,5% Cu.

Fig. 3 Feedstock – ø1,6 mm wire section of tin, antimony and cooper alloy.

The particle size distributions were estimated with the usage of laser device *Mastersizer* which evaluates diffraction of particles. Investigated particle sizes were of the range 0,49-878,67 µm [7].

3. The properties of powders

Powders in the delivery state should be dry and contamination-free. Of course, the suitability of the powders is determined by other factors as well, they are: size, shape, microstructure, phase composition, flowability, weight distribution of the particles depending on their size, temperature and pressure of gas, nozzle distance from the ground and other factors [2]. Primarily the greater dispersion of powders is obtained with increased gas pressure, greater flow and decreased distance of the nozzle from the stream of molten metal. Applied pressure and flow rate of the gas amount respectively: $14 \cdot 10^5$ Pa and 50–150 m/s [6]. Nevertheless, the key attention in the presented study was given to the size and shape of powders.

After the spraying process, obtained powders are of different sizes – ranging from a few microns to several millimetres. The welding processes require powders with a narrow particle size range. Exemplary particle sizes are as follows [2], [6]:

– fused flame: 20-71 µm,
– fused plasma: 71-160 µm or 71-320 µm (depending on the alloy composition and the equipment),
– thermal spray: 10-56 µm.

Object of interest in the following article were powders with grain size of 50 µm ≤ *d* < 160 µm (Fig. 4). Powders with diameters less than 50 µm and above 160 µm were classified as waste for processing. Separation of sprayed alloy to individual grain fractions is possible thank to sieves for powders separation.

Fig. 4 Powder obtained after spraying. Fraction 50 µm ≤ *d* < 160 µm.

The specific feature of powders manufactured by the spraying method is their spheroidal shape (Fig. 5) with relatively smooth surface.

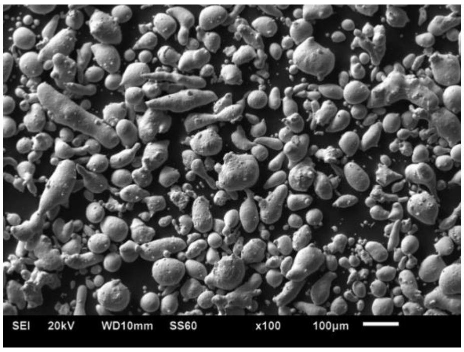

Fig. 5 Morphology of the powder of tin, antimony and copper, obtained after the metal spraying from the liquid phase. Spheroidal shape of particles characteristic of the method of gas atomization. Fraction 50 µm ≤ *d* < 160 µm.

4. Volume fraction

The experimental activities covered the investigation of sprayed powder of tin, antimony and copper due to their volume fraction (Fig. 6 and Fig. 7). The required range of grain size was in the range 50 µm ≤ d < 160 µm. According to the obtained results, it may be concluded that applied method of metal spraying from the liquid phase enables ease control of grains geometry, what is confirmed by presence of one great peak, undisturbed by other finer deviations (Fig. 6). Moreover, the waste of the powder in the amount of 8,58 % (Fig. 7) may be assumed as low, especially taking into account the volume of fraction appropriate with the initial requirements - 56,06 %. Applied gas atomisation method allowed to reach high quality of material with, at the same time, minimal material waste. Results indicate process efficiency. Availability of results for the individual fractions confirms ease separation of the sprayed materials into individual grain fractions. This means that with this method allows easily control the size of the grains.

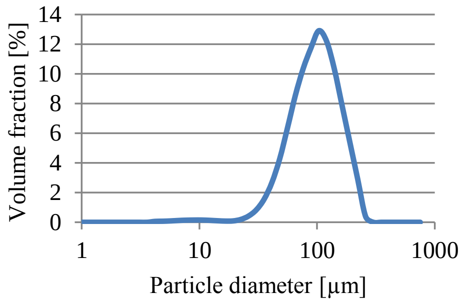

Fig. 6 Volume fraction of investigated powder depending on the diameter of atomized particles.

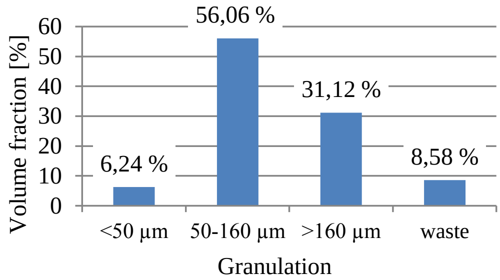

Fig. 7 Volume fractions of investigated powder depending on its granulation.

5. Chemical composition

The volume fraction is determined significantly by the used material. Comparing own results (no. 1 in Tab. 1) and literature data (no. 2-6 in Tab. 1) [4], the diversity of powders volume fractions, depending on their chemical composition, is confirmed. Taking into account three fractions ranges: 70-120 µm, 120-200 µm and 200-500 µm and both pure metals and alloys, it may be concluded that powders do not reveal the same tendency in the presence of chosen fractions. It indicates that usage of each powder in chosen field should be preceded a thorough investigation of powder before its application. It again shown the great meaning of step of powders manufacturing.

Tab. 1 Volume fraction of selected metal and alloy powders [4].

	Powder	The average powder volume fraction [%]		
		75-120 µm	120-200 µm	200-500 µm
1	89%Sn + 7,5%Sb + 3,5%Cu	34,99	35,65	3,26
2	Cu	5,50	48,50	13,50
3	Ag	16,00	36,00	28,00
4	CuP6Sn5Sb2	10,00	33,00	12,00
5	CuP7Ni10Sn6	16,00	27,00	7,00
6	AgNi20	20,80	29,70	14,30

Chemical composition of the sprayed material, influence not solely the volume fractions, but also their melting points. This, in turn, decides about the geometry of the particles. Studies [6] showed that a more regular shape and lower powder areas are obtained at higher temperatures of the molten metals.

6. Conclusions

Based on experimental results, it may be concluded that:

1. Method of spraying from the liquid phase allows ease control of the geometry and size of grains. Specific feature of particles sprayed by the means of gas atomisation technique is their spheroidal shape with relatively smooth surface (Fig. 5). Ease separation of grains (conducted by the sieve analysis) enables to distinguish individual grain fractions, which met the proposed requirements (50-160 μm) for 56,06% of the initial powder and with low waste level (8,58%). It indicates process efficiency.

2. Comparison of volume fractions of sprayed alloy and other metals and alloys, provided by the literature [4], indicated on great diversity of powders volume fraction, depending on their chemical composition. It clearly shows that each powder have to be individually studied before its application in chosen area.

7. Summary

Object of interest was the method of metal spraying from the liquid phase, known also as the technique of gas atomization. The literature study covered introduction to its technology, methodology and brief powder characteristic. The spraying process takes place in three stages: first liquid metal met with inert gas stream, which transform shape of molten metal into conical surface. Finally the stream breaks up into spherical droplets, which subsequently solidify. [6] Molten metal is transported to the spray tower by the spray nozzle with the support of de-dusting equipment. Key factors in the assessment of produced powders are their geometry and size. They depend on application of material.

The experimental part covered powders manufacturing, made of an alloy of tin, antimony and copper. Powders were divided into fraction below 50 μm, 50-160 μm and above 160 μm thanks the sieve analysis. Powders revealed spheroidal morphology, as suspected for the method of gas atomization. The experimental activities included also assessment of volume fraction of produced powders. The experimental results and literature data [4] were confronted – the influence of chemical composition to the volume fraction of powders was investigated.

To sum up, it may be stated that the method of metal spraying from the liquid phase has many advantages – particularly worth of mention are: easily controllable grains geometry, process efficiency, possibility of obtaining powder with complex chemical composition, homogeneous chemical composition in the whole grain volume. In the reference to the papers [4] and [6], derived from more than a decade, it may be stated that authors of contemporary studies correctly assessed the gas atomization method as the technique with great potential and prospects for development.

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