Characterization of spherical stainless steel powders prepared by electric arc spraying process

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Abstract. Spherical powders were obtained by electric arc spraying of stainless-steel wire. The effect of the electrical power during the arc spraying process was investigated. The fractional composition of the obtained powder was determined by laser diffractometry. Scanning Auger microprobe was used to study surface morphology of the powder particles. The obtained spherical stainless-steel powders will be used to fabricate products by additive manufacturing methods.

1. Introduction
Stainless steel, as a class of ferrous alloys, is widely well-known for corrosion- and creep resistance, and for high-temperature applications. Due to the demand increasing of powder metallurgy components made from stainless steel in a variety of applications, including aerospace, automotive, chemical processing and biomedical field, this material became of great interest in the research domain. To obtain spherical metal powders, various methods can be used: gas atomization, plasma atomization, and plasma rotating electrode process. In these methods, the material of the tungsten cathode, the copper anode or the copper water-cooled crucible can get into the sprayed powder [1]. In this work, the properties of spherical stainless-steel powders prepared by the electric arc spraying process were studied. The main advantage of this method is the ability to obtain low impurity powder. The electric arc wire spraying method allows to obtain from 5 to 30 kg of powder per hour. In this work, the stainless-steel composition Fe-18%Cr-10%Ni-1%Ti (AISI 321) was used. Stainless steel powders are used to manufacture complex shapes products by different additive methods: selective laser melting, direct metal laser sintering or electron-beam melting [2]. The properties of the end product are determined by both characteristics of the metal powder and the type of the 3D printing process [3].

The aim of this work is to determine the properties of stainless steel Fe-18% Cr-10% Ni-1% Ti obtained by electric arc spraying. The wire was sprayed with an argon jet by means of the arc spraying process in the air.

2. Methods and materials
A commercial wire of Fe-18%Cr-10%Ni-1%Ti was chosen for spraying and atomization. This wire has a diameter of 1.6 mm. The chemical composition of steel is given in Table 1.

Table 1. The chemical composition of steel.

| Cr, % | Ni, % | Cu, % | Mn, % | S, % | P, % | C, % | Si, % | Ti, % | Fe, % |
|-------|-------|-------|-------|------|------|------|-------|-------|-------|
| 18    | 10    | <0.3  | <2    | <0.02| <0.035| <0.12| <0.8  | 1     | Balance |

The spraying equipment was the twin-wire arc spray system C-16-CT(M) (GMBh "Thermal-Spray-Tec", Moscow, Russia) with the arc spray gun. The maximum power of the arc spray gun is 29 kW. The arc spray gun had a cylindrical nozzle with a diameter 4.5 mm. The argon was used as the spray gas with the average flow range of 1 m³/min. The spray process was in the cylindrical pipe in the air. The current was changed during the spraying process. The principal scheme of arc spraying process is given in Figure 1.

![Figure 1. Principal scheme of arc spraying process.](image)

The particle size distributions of powders were determined using an Analysette 22 NanoTec laser diffraction particle size analyzer from Fritsch. The particle size analyzer measuring cell contains the sample particles prepared by the dispersion unit which are irradiated with laser light. By changing the spacing between the detector and measuring cell, a different angle range of the scattered light is detected. The particle size distribution is calculated from this data.

The Leco TC-600 is a software-controlled instrument that measures both nitrogen and oxygen in a wide variety of metals, refractories, and other inorganic materials. The inert gas fusion principle is employed. A weighed sample, placed in a high-purity graphite crucible, is fused under a flowing helium gas stream at temperatures sufficient to release oxygen, nitrogen, and hydrogen. The oxygen in the sample combines with the carbon from the crucible forming primarily carbon monoxide (CO). In some instances, depending upon sample type and furnace temperature, some oxygen can be released directly as carbon dioxide (CO). The nitrogen present in the sample releases as molecular 2 nitrogen, and any hydrogen present is released as hydrogen gas.

Scanning Auger microprobe JEOL JAMP-9500F was used to study the surface morphology and to carry out the fractographic investigation of the specimens after the static tests. Powder particles were placed on double-sided carbon tape.

3. Results and discussion
The particle size distribution of spherical powder is shown in Figure 2. As can be seen, the particle size of the powder is in the range from 20 to 125 microns. Moreover, more than 60% of the powder particles have a size of 60 ± 10 μm.

![Figure 2. Particle size distribution of the Fe-18%Cr-10%Ni-1%Ti powder.](image)

The determination of the content of gas-forming impurities in the initial wire and the obtained samples showed that during the spraying process, the powder particles are actively oxidized. So the oxygen content in the powder samples is more than 5%, while in the original wire the oxygen content was less than 0.005%. The nitrogen content in the powder samples and wire was 0.09% and 0.01%, respectively. The amount of carbon in the powder slightly decreased compared to its content in the wire - 0.05% and 0.07%. Since the process of spraying the wire took place in the air, the resulting particles were strongly oxidized. The carbon decreasing in powder particles compared to the wire is also due to oxidizing processes.

The study of the powder morphology was carried out using a JEOL JAMP-9500F scanning Auger microprobe. Images presented in figure 3 show that most particles have a spherical or near-spherical shape. However, there are some defects on the particle surfaces such as pores, holes, and cracks. The holes on the surface were formed due to the impacts between particles. There are no satellites on the surface of particles.

Analysis of this data showed that spherical particles can be obtained by the arc spray process. Particle size distribution complies with the requirements of the additive methods. To reduce particle oxidation, the atomization process must be carried out in an inert atmosphere.
Figure 3. Images of Fe-18%Cr-10%Ni-1%Ti powder with typical spherical and near-spherical morphologies. a) – the scale bar represents 100 μm and the image is roughly 450 μm wide; b) – the scale bar represents 400 μm and the image is roughly 1800 μm wide; c) – the scale bar represents 200 μm and the image is roughly 900 μm wide.

4. Conclusion
The powder obtained by the electric arc spraying process from the Fe-18%Cr-10%Ni-1%Ti wire has a spherical and near-spherical shape. The spherical powder was formed during the solidification of liquid steel drops. The majority of particles has a size distribution from 20 to 60 μm. Therefore the particle size distribution complies with the requirements of the additive methods. Increased oxygen content impact on the morphology of the surface particles powder due to the mix of the argon and oxygen from the air.

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References

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