IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

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To cite this article: B S Ermakov *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **826** 012007

IOP Conf. Series: Materials Science and Engineering **826** (2020) 012007 doi:10.1088/1757-899X/826/1/012007

Regulation of powder particle sizes during plasma spraying

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Abstract. One of the factors constraining the development of 3D technologies is the shortage of powders for additive machines. St. Petersburg Polytechnic University (SPbPU) is developing the design and production of plasma nozzles to produce metal powders and alloys intended for additive machines. The article discusses the results of studies of the effect of pressure powders and flow rate generated in the spray chamber in the production of powders from 08Cr18Ni10Ti and CrNi60BWoTi alloys on the particle size distribution.

1. Introduction

The development of industry at the present stage can be characterized as a gradual departure from the creation and production of large-scale batches of machines and mechanisms with an average set of characteristics for the production of single and small series of equipment with the properties that best satisfy a particular customer. This way of development requires changes in a number of technological processes for the production of individual parts and assemblies, machines and mechanisms. Such changes, first of all, include the gradual replacement of subtractive processing technologies, for example, cutting the workpieces using additive manufacturing technology using the method of three-dimensional printing (3D). Wohlers Associates research showed that, in the world in 2014, the additive technology market amounted to about $ 3 billion with the average growth rate of about 20-30%. Probably in the near future, the market volume will be able to reach 16 billion dollars. The most active substitution of subtractors by 3D technology is observed in the actively developing aviation industry, shipbuilding, power engineering, including in dentistry and reconstructive surgery [1-3].

Today, Russia lags behind the leading countries of the world in the development of additive technologies due to the lack of domestic production of additive machines and the lack of a domestic base for the production of metal powders of small fractions. Today, most Russian companies use powders, which are mainly imported by foreign companies. According to academician E. N. According to Kablov, about 20 tons of powders is necessary per year for the Russian fleet of additive technologies equipment; it should be take into account that the volume of consumption of powders will constantly increase [1]. The production of powders is a major challenge for additive technologies. The quality of the powder depends primarily on the quality of the resulting parts. At present, especially with the introduction of sanctions, the problem of obtaining powders for additive technologies has become the most acute problem hindering the development of this technological direction in our country.

2. Materials and methods

Sputtering is the production of metal powders by dispersing a melt under the action of inertial forces by a jet of gas, liquid or plasma. Melting, spraying and solidification of the required metals and alloys are used in the production of powders. Melting furnaces of various types produce melting of metals and alloys under the action of an electric arc or plasma. Spraying is most often carried out using a stream of water at a high pressure, or in streams of inert and neutral gases. Spraying in various ways is currently the basis of high-quality metal production technologies. Such powders, subject to specific requirements, include a spherical shape of the particles, the particles pure from oxides and the volume of metal from foreign impurities, rapid crystallization, homogeneous microstructure [4]. Most often, when obtaining powders, liquid metal spraying is used. The undoubted advantage of this method can be consider the relative simplicity and cheapness of the technological process of obtaining metal powders with a wide temperature range of melting. The process of spraying a metal stream using a gas stream is either a gas stream that coaxially flows around the melt stream, or a stream of flowing gas directed at a given angle to the axis of the jet. Otherwise there is also a gas stream directed perpendicular to the axis of the jet. It is known that in one of the most efficient sputtering processes, the process takes place at a gas flow temperature that is equal to or greater than the melt temperature. However, if the temperature reaches 1500 °C or more, the creation of such conditions is difficult, because there are difficulties in heating the gas blast, and, in addition, become more complicated and expensive installations used for spraying. In such cases, it is justified to use the plasma method, when the spray jet of molten metal or wire is due to the kinetic energy of the jet of high-temperature plasma. In addition, the use of plasma atomization allows to obtain spheroidal powders. Wire or powder in this method can be as a source of raw materials. The plasma jet melts the initial billet, the droplets of the material are sprayed, after which the solidification of single-crystal particles occurs [3, 4]. By adjusting the energy parameters of the plasma flow [3], for example, increasing the temperature and kinetic energy of the gas flow, it is possible to produce a meltdown of the melt jet into smaller particles. The size and shape of the resulting powder particles can be adjusted, taking into account the physical properties of the sprayed material and the diameter of the sprayed wire. By increasing the diameter, the number of small particles in the powder can be reduced by increasing the mass of the melt entering the spray zone. Therefore, the solution of the problem of obtaining particles of the required size and increasing the yield of marketable products is one of the most important tasks in the development of technology and modes of plasma spraying.

The process of formation of a metal particle when sprayed in a low-temperature plasma can be conditionally divided into several successive stages, during which there is a formation of fine particles, the subsequent movement and heat exchange in the plasma flow and in the medium, and then the subsequent collection of particles. First, the feedstock is heated, and then it melts due to the heat of the plasma arc. Comparison of the residence time of the droplet during melting of the welding electrode or welding wire in the environment of protective gases with this method shows that at the end of the wire in this case it stays less time. The action of the arc pressure forces, as well as the reactive forces arising from the evaporation of metal and the release of gases, gravitational forces, surface tension forces, electrodynamic forces ensures the separation of the droplet from the end of the wire. At the moment of separation, the drop is characterized by certain dimensions, temperature and initial velocity [5]. The average diameter of the droplet can be estimated by the following formula:

$$d_d = \frac{\pi \sigma d_1 d_2}{M_1 V_1 + M_2 V_2}$$

where σ is the surface tension of the material feedstock in the contact zone of the metal and the plasma arc, d_1 – feedstock diameter, d_2 is the diameter of the nozzle of the plasma torch, M_1, and M_2 is the mass of the plasma stabilizing gas, V_1 and V_2 – speed of the plasma stabilizing gas.

After the drop leaves the plasma stream, it moves in a controlled environment of a protective gas, the temperature of which does not exceed several tens of degrees, gradually crystallizing and cooling. Depending on the spray conditions, the melting temperature of the sprayed material, the length of the free path of the particle inside the spray chamber (before impact with the bottom of the chamber), the protective medium may have a constant, normal or increased pressure. It can be either stationary or movable with the speed of movement directed towards the movement of the particle (flow). When certain counterflow parameters are reached, it is even possible to stop and change the direction of particle motion [6].

SPbPU is engaged in the development of equipment and technology for plasma spraying of metals and alloys and obtaining powders for additive machines. A number of plasma atomizers based on different atomization schemes with one or more plasma torches with horizontal and vertical solid feedstocks have been created.

3. Results and discussion

This paper presents the results of experiments on the melting of stainless steel wire 08Cr18Ni10Ti and alloy Woh98 (CrNi60BWoTi). (0.1%C, W-15.7%, Cr-25.2%, Fe -3.7%, Mo -1.4%< (Ti+V+Nb – 0.9%, nickel – base) with free run of particles and counterflow of protective gas-argon, the speed of which was determined through the volume of gas supply to the nozzles of the fluidized bed mechanism to create a counterflow. Also, the pressure in the spray chamber was regulated, which was P_0 = 1 ata - free flow of gas through the chamber and P_1 = 1.25 ata - work at high pressure. The mode of spraying was unchanged for both materials, spraying in an arc of indirect action: U-130 B, I-165 A, the volume of plasma-forming gas was 1800 l / h, the angle of wire feed – 90^0 to the direction of the gas-plasma flow. The volume of gas supply to the fluidized bed mechanism was V_0 = 0, V_1 = 5 and V_2 = 10 liters per minute.

Table 1. Particle size distribution of powders in the free run

Diameter of powder particles (not less than) mkm	The amount of powder, % Steel 08Cr18Ni10Ti		The amount of powder, % Alloy CrNi60BWoTi	
	P_0	P_1	P_0	P_1
315	14.3	9.1	12.7	9.0
200	21.1	12.8	16.3	13.4
140	17.8	17.0	18.1	15.2
100	12.8	17.6	13.2	15.5
80	11.3	15.7	12.0	15.4
63	10.5	12.2	11.7	13.0
40	6.2	8.0	9.1	10.1
20	5.9	6.1	7.3	7.0
Less than 20	1.0	1.5	0.6	1.4

Tables 1 and 2 present the results of the granulometric analysis of the obtained particles under the conditions of free run of particles (table 1) and table 2 – when creating a counterflow. The particle size and their percentage were determined by sieving the total mass of the sprayed powder on vibrating screens with sieves of appropriate cell sizes.

Increasing the pressure in the spray chamber allows increasing the share of commercial powder products, reducing the average diameter of powder particles.

Table 2. Effect of composition of powders at counterflow velocity (P_0 = 1 ata)

Fraction, mkm*		The amount of powder, %		The amount of powder, %	
		Less than steel 08Cr18Ni10Ti		Alloy CrNi60BWoTi	
		V_1	V_2	V_1	V_2
315		13.6	13.2	12.2	12.0
200		20.0	19.2	16.0	15.9
140		17.8	17.6	18.0	17.1
100		13.2	13.4	13.4	13.2
80		11.7	12.2	11.9	12.6
63		10.8	11.2	11.8	12.2
40		5.8	6.1	8.8	9.5
20	5.8	5.7	7.3	6,5	
Less than 20	1.3	1.4	0.8	1,0	

Creating a counterflow in the spray chamber has a very little effect on the percentage distribution of powder particles of both materials, but contributes to the production of powders of the best geometric shapes – the powders obtained when creating a counterflow have an almost ideal spherical shape. In the powder mass there are practically no satellites, fused with each of the powder particles (figure 1).


a)


b)

Figure 1. The types of obtained powder: a) steel 08Cr18Ni10Ti; b) (CrNi60BWoTi)

4. Conclusion

On the basis of the conducted research, dependence of the sizes of the received powders on the size of excess pressure in the chamber of atomization was shown. The share of commodity production (powders with a diameter of 80-20 mkm) at normal pressure was 33.9% for steel 08Cr18Ni10Ti, 39.8% - for alloy CrNi60BWoTi increased by 1.25% at a pressure of 42 and 45.5%, respectively. Thus, the way of creating excess pressure in the spray chamber can be recognized as promising for further research.

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