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PROGRESS IN COPPER ALLOY ADDITIVE MANUFACTURING TECHNOLOGY

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Abstract: The rapid development of additive manufacturing technology has provided new development impetus for copper alloy manufacturing technology. This article mainly summarizes the methods of different copper alloy additive manufacturing processes at home and abroad in recent years, analyzes the problems encountered in the additive manufacturing research process such as the easy grain size of additive manufacturing samples, the easy formation of cracks, and the easy introduction of impurities, and compares them. Microstructure and mechanical properties of copper alloy samples prepared under different additive manufacturing processes. On this basis, this paper focuses on the progress of copper alloy additive manufacturing technology research in different additive manufacturing process methods, and compares the microstructure and mechanical properties of additive manufacturing samples and traditional casting samples. Finally, the research progress of copper alloy additive manufacturing technology is summarized, and its development prospects and development directions are prospected.
Keywords: Copper alloy; Additive manufacturing; Mechanical properties; Processing technology

1 COPPER ALLOY ADDITIVE MANUFACTURING TECHNOLOGY AND PROCESS

Additive manufacturing technology is also called rapid prototyping technology, 3D Printing technology [1] has the characteristics of high raw material utilization, no need for fixtures, low cost, and short cycle time from product design to finished product processing. It is widely favored in material processing, traditional manufacturing, and aerospace precision and complex components, and has good Its application prospects have also become one of the current research hotspots in universities and research institutes [2]. Copper alloys are widely used in electric power, aerospace, electronics and other industries due to their good electrical conductivity, thermal conductivity, casting and corrosion resistance properties [3-4]. As the product market cycle shortens, technical levels improve, and the concept of green environmental protection continues to be deeply rooted in the hearts of the people, there are higher requirements for product processing technology, processing costs, and environmental protection [5]. Traditional manufacturing technology has great limitations in this regard, while additive manufacturing technology has obvious advantages. Copper alloy additive manufacturing technology has become one of the research hotspots . Domestic and foreign scholars have studied the process methods, mechanical properties, forming microstructure, and additive manufacturing technology. Related research has been conducted on the additive manufacturing technology of copper alloys in terms of the physical properties of the material (electrical conductivity, thermal conductivity, density) and other aspects.
There are many types of copper alloys with different material properties. It is particularly critical to select a suitable heat source. At the same time, the state of the copper alloy material is also an important factor affecting the performance of additive manufacturing [6-7]. Research on relevant literature at home and abroad has found that copper alloy additive manufacturing technologies generally include the following: laser additive manufacturing copper alloy technology [8-13], electron beam additive manufacturing copper alloy technology [14-20], arc additive manufacturing Copper alloy technology [21-22], ultrasonic additive manufacturing copper alloy technology. [23].

1.1 Laser Additive Manufacturing Copper Alloy Technology

Laser Additive Manufacturing (Laser Additive Manufacturing (LAM) technology is an integrated manufacturing technology that takes into account the requirements of precise forming and high-performance forming, including laser engineered net forming (Laser Engineer Net Shape, LENS)[8] and Selective Laser Melting (SLM)[9-13].
Copper alloys have superior thermal and electrical conductivity, as well as low strength, dense High strength and other characteristics, often used in combination with structural materials to improve parts The purpose of comprehensive performance, such as nickel alloy. In engineering applications, can Manufacturing this kind of bimetallic structure with comprehensive properties has become a restricted project The technical key to the application. To solve this problem, American mechanical and materials engineers The Bimetallic Materials Research Laboratory of Cheng University uses laser engineering to produce LENS technology, the brand name is Inconel in the United States 718 Nickel Alloy Cladding GRCop-84 on board Copper alloy, realizing nickel-copper alloy double gold Made of a structural structure, the good thermal conductivity and electrical conductivity of copper alloy make up for Nickel alloy has poor thermal and electrical conductivity. The study shows: ① Very It is difficult to directly clad copper alloy powder on the nickel plate; ② When adding copper The mass fractions of alloy powder and nickel alloy powder respectively account for 50% transition layer can achieve good surface morphology, continuity between layers and structural integrity Good cladding results. At the same time, researchers measured thermal diffusion. When the temperature of the bimetal structure is 50~300°C, the thermal diffusion rate is 11.33 mm2/s, compared to the thermal diffusion speed of nickel alloy 3.20 mm2/s, increase 250%; compared to nickel alloy, the electrical conductivity of the bimetal structure increases by 300%. The significance of this

research is that it not only provides a method for preparing copper-nickel alloys Bimetal manufacturing method, and is useful for manufacturing multi-metal structures with various properties The research provides a reference direction [7].
Additive manufacturing of copper alloy parts is another additive manufacturing research direction, which focuses on the impact of process parameters on the density, microstructure and mechanical properties of the prepared samples. Germany adopts Cu-10Sn Powder was used as raw material for additive manufacturing through selective laser melting technology (SLM), and its microstructure and mechanical and mechanical properties were compared with those of cast samples. The results showed that SLM The phase obtained is the same as casting, but the strength is better and the structure is finer and more uniform [8]. The State Key Laboratory of Powder Metallurgy of Central South University used Cu-15Ni-8Sn raw material powder prepared by gas atomization as raw material and used selective laser melting for additive manufacturing. It studied the effect of laser energy density on the melting and macroscopic forming of Cu-15Ni-8Sn raw material powder. Impact. When the energy density is 35 J/mm3 When the energy density increases to 70 J/mm3 When the energy density reaches 142 J/mm3, the melting tunnel becomes longer, the holes and unmelted powder particles are reduced, and the forming becomes better. When the melting tunnels in the same layer form a continuous state, only holes are found in very few areas, the powder is completely melted, and a Cu-15Ni-8Sn material with a density of 99.4% is obtained [10]. SLM Energy input has a great impact on copper alloy powder additive manufacturing forming, SLM It can improve the mechanical properties of copper alloys and refine the grains. Szemkus et al. [12] set the size as 25~150 μm Mix copper alloy powder and chromium alloy powder to obtain 75%Cu-25%Cr (mass fraction), which is manufactured using laser additive manufacturing Cu-Cr Electrical contact products, as shown in the figure 1 As shown, the following parameters were used for sample preparation: laser scanning speed was 400 mm/s, energy was 220 W, and OM and SEM were used to for manufacturing Cu-Cr The parts were analyzed for porosity and the lowest porosity was obtained at 3.3%. However, there were shortcomings such as low production efficiency and high processing cost. Szemkus [12] predicted that using electron beams as heat sources can improve productivity.

(A) Laser Additive Manufacturing (B) Traditional craft manufacturing

Fig. 1 Copper alloy products under SLM and traditional processes[12]

Russia[12] Prepared by atomization method Cu-Cr-Zr-Ti Alloy powder, selective laser melting additive manufacturing Cu-Cr-Zr-Ti sample block, its density reaches 97.9%, the grain size range is 30~250 μm, the growth direction is along the additive manufacturing direction, after solid solution aging The grains are coarser than before solid solution aging, and the room temperature tensile strength is 195~211 MPa, elongation is 11%~16%; tested at 600 and 800 ℃, the tensile strength and elongation are lower than room temperature.
Unlike other metals, copper is also widely used in circuits, and there is also research on additive manufacturing of circuits. Hou et al. [11] used a mixture of copper alloy powder and high-density polyethylene powder as materials, and used a selective laser as a heat source to create a 3D conductive track. They studied the effect of the volume ratio of copper alloy powder and high-density polyethylene powder on the resistivity of the conductive track. Comparing the impact of single-channel scanning and raster scanning on the resistivity of conductive rails, the volume of copper alloy powder is 60%, and the lowest resistivity is $(1.9\pm0.1)\times10^{-4}$ Ω·cm, using raster scanning at the same ratio, the resistivity is reduced to $(0.35\pm0.04)\times10^{-4}$ Ω ·cm, using this parameter to successfully realize 3D circuit manufacturing, providing a new idea for equipment circuit manufacturing.
Copper alloy laser additive manufacturing technology generally uses powder as raw material. The size of the powder is roughly between 10 and 150 μm. The powder preparation method is mostly atomization. The shortcomings of laser additive manufacturing are mainly manifested in the difficulty in achieving zero porosity, difficulty in controlling the structure, high processing costs, low efficiency, high requirements for additive powders, and strict protective atmosphere. Laser additive manufacturing is a popular processing method in copper alloy additive manufacturing technology research. Laser has high energy density and good parameter controllability. It is favored by researchers. After technological improvement and process optimization, copper alloy laser additive manufacturing Material manufacturing is of great value.

1.2 Electron Beam Additive Manufacturing Copper Alloy Technology

Electron beam additive manufacturing (EBM) technology includes electron beam fuse sinking Accumulation forming technology and electron beam selective melting technology [1]. Electron beam additive manufacturing The manufacturing characteristics are high cladding efficiency and vacuum chamber protection of workpieces, but for For light alloys, in vacuum, the bombardment of electron beams evaporates the metal, and the pores in the internal structure tend to increase [2]. For pure copper, pure copper is Light has high reflectivity and absorption rate is less than 2%. Therefore, electron beam is used Additive manufacturing technology has potential for additive manufacturing of pure copper [14].

Germany has a purity of 99.95% copper is additively manufactured using electron beam selective melting technology. It is not completely melted at low electron beam energy, and there are typical pores, tunnels, and cracks [14]. Murr et al. [15] in the United States carried out electron beam additive manufacturing of pure copper powder, TEM Analysis found that high-density dislocations and Cu2O precipitated phases were produced. Ramirez et al. [16] further determined the location of the Cu2O precipitated phase and found that it appeared at the intersection of normal grains and sub-grains, and produced depositional dislocations, which had a significant strengthening effect on the microhardness of the structure, with a hardness as high as HV88. The hardness of a copper plate with a purity of 98.5% is HV57. In additive manufacturing of alloy powders with widely different melting points, it is easy for high-melting-point metal powders to fail to melt and become embedded in the structure, causing defects. Momeni [20] used mixed powder 75%Cu-25%Cr (mass fraction) and used electron beam as the heat source for additive manufacturing. When the Cu alloy powder melts, the Cr powder remains in a solid state. The powder requires extremely high temperatures to melt. due to extremely fast Melting and cooling cause extremely fine Cr particles to be distributed in the Cu structure.

In addition to manufacturing high-density parts, additive manufacturing is also researching the creation of uniform network structures, which has potential in applications such as thermal control or heat exchange. Ramirez [18] used electron beam additive manufacturing to manufacture open honeycombCopper mesh and random foam copper mesh, diameter 65 μm The copper powder contains Cu2O and the purity is 99.8%. Computer-aided design model (CAD) was used to prepare open honeycomb copper mesh with density ranging from 1.20 to 6.67 g/cm3, with the highest density reaching 8.02 g/cm3. Lodes et al. [19] adopted a purity of 99.94% Copper alloy powder additive manufacturing heat exchanger; the good heat dissipation performance of pure copper leads to a large amount of heat loss, becoming the biggest obstacle in additive manufacturing.

In addition to using powder as a raw material for additive manufacturing, you can also use Use wire as material. Adopted by the laboratory of Harbin Institute of Technology in China [17] T2 copper alloy with a diameter of 1.2 mm and 304 stainless steel wire are used as materials material, 304 stainless steel wire is clad with two layers, and then copper alloy wire is used to additively manufacture it. Formation; α phase appears in the first layer of massive structure, and with the number of cladding layers As the layer increases, the amount of iron elements and the size of the α phase gradually decrease. After more than 3 layers, it is difficult to find the α phase; the α phase is spherical and dendritic. If ε phase does not exist In dendritic tissue, it exists in spherical tissue. The α phase is deposited phase, the ε phase is a diffusion phase; the low cooling rate and orderly transformation process make the melt FeCu4 metastable phase is produced during the coating process, and it is inferred that the FeCu4 metastable phase is based on the sphere like black spots are present in iron, but in the first layer, copper alloy with stainless steel edge There are cracks in the world. Dissimilar metal additive manufacturing of bimetal structures cannot be avoided Avoid the generation of new phases or intermetallic compounds, which is very important for bimetallic structures. Performance has a big impact.

As a high-energy-density heat source, electron beams have attracted much attention from researchers. Sub-beams have strict requirements on the vacuum environment and can easily cause process characteristics such as pores and thinning. Characteristics, these characteristics will also appear in copper alloy additive manufacturing. In heterogeneous powder In the hybrid additive manufacturing process, it is necessary to focus on the melting point of the powder to avoid The phenomenon of high melting point powder not melting occurs; for copper alloy electron beam additives Manufacturing optimization control aspects are rarely covered. There are many studies on pure copper additive manufacturing, while there are few studies on additive manufacturing of other copper alloys. In recent years, copper alloys at home and abroad have Some studies on high-energy beam additive manufacturing technology are shown in Table 1.

Table 1 Current laser/electron beam additive manufacturing of copper alloys

Additive manufacturing technology	material ingredient	Powder/silk size/μm	author
SLM	Cu-10Sn	85±15	Scudino et al[9]
SLM	Cu-15Ni-8Sn-0.2Nb	35	Zhang et al[10]
LENS	Nickel Alloy 718/GRCop Copper Alloy Powder	45~150	Onuike et al[8]
SLM	75%Cu-25%Cr (mass fraction)	25~150	Szemkus et al[12]
SLM	0.50-0.70Cr, 0.02-0.05Zr, 0.02-0.05Ti, the rest is Cu	16~79	Popovich et al[13]
SLM	Copper alloy powder (Sigma-Aldrich)	10	Hou et al[11]
EBM	T2	Φ1.2 mm	Shu et al[17]
EBM	Purity is 99.8%Cu	40~100	Ramirez et al[16]
SEBM	Purity is 99.94%Cu	45~106	Lodes et al[19]
SEBM	Purity is 99.95%Cu	50~110	Guschlbauer et al[14]
SEBM	75%Cu-25%Cr (mass fraction)		Momeni et al[20]

1.3 Arc Additive Manufacturing Copper Alloy Technology

Arc additive manufacturing technology optimizes traditional arc welding technology An additive manufacturing technology formed, such as tungsten inert gas shielded welding (TIG), melted inert gas welding (MIG), plasma arc welding (PA). Arc additive manufacturing technology has the advantages of low cost, high cladding rate and high production efficiency. The advantage of short cycle time, but the arc is difficult to control. Additive Manufacturing in Copper Alloys fields, arcs are rarely used as heat sources.

Liu et al. [21] used a molten extremely inert gas shielded welding arc as the heat source, with a diameter of 0.8 mm of SG-CuSi3 silicon bronze and a diameter of 1.2 mm of ER70S-6 mild steel for cladding wire, in mild steel Q235B A single-channel multi-layer low carbon steel-silicon bronze dissimilar (double) metal component was deposited on the board. It was found that the Cu element did not diffuse on the low carbon steel side, while the Fe element was on the silicon side. The bronze side gathers to form granular and lumpy shapes, and the Fe element zone and mixed zone appear on the silicon bronze side. Si element aggregates, low carbon steel-silicon green The copper interface achieves good metallurgical bonding without cracks or holes. same Such high-energy beam additive manufacturing processes will cause element segregation and new phase formation. DONG et al. [22] used TIG arc as the heat source, Cu/Al double wire and horizontal The direction is symmetrical at an angle of 30° and the wire is fed simultaneously. The wire feeding speed of Cu wire is 1300 mm/min, the wire feeding speed of Al wire is 311 mm/min, achieving real-time Additive manufacturing of copper-rich Cu-Al alloys, studying the microstructure of copper-rich Cu-Al alloys Structure and mechanical properties. This in-situ Cu/Al alloy additive manufacturing method The alloy composition can be controlled by changing the wire feeding speed. After subsequent heating Processing to achieve tissue homogenization and strengthen mechanical properties is a kind of New method for making Cu-Al alloys.

As a heat source, arc is less researched in the field of copper alloy additive manufacturing. The arc deposition efficiency is high, the wire utilization rate is high, and the cost is low. There are few restrictions on the size of parts, and it is easy to repair parts. Compared with casting, no molds are required. The design has a fast response speed and is suitable for small batch production. However, copper alloy arc additive manufacturing needs further research.

1.4 Solid Phase Additive Manufacturing Technology

Different from the melting and then additive manufacturing method of laser, electron beam, and arc as heat source, ultrasonic additive manufacturing (UAM) is a solid-phase additive manufacturing process, using ultra-thin metal such as metal sheets and foils as raw materials, and high-power The ultrasonic equipment converts ultrasonic energy into mechanical vibration and transmits it to the metal foil through the clamping handle, causing the two metal foils to vibrate relative to each other and generate heat, which promotes the mutual diffusion of metal atoms between the interfaces, forming solid-state physical metallurgy, and realizing layer-by-layer additive manufacturing. NORFOLK et al. [23] used copper alloy foil as material and used ultrasonic additive manufacturing to achieve a 6-layer completely dense non-porous structure. Research on copper alloy solid-phase additive manufacturing technology is very lacking, and there is still a lot of work to be done in this area.

2 MICROSTRUCTURE AND PROPERTIES OF ADDITIVELY MANUFACTURED COPPER ALLOYS

2.1 Microstructure and Physical Properties of Additively Manufactured Copper Alloys

The copper alloy additive manufacturing process is different from the traditional processing process. There are also differences in macro and micro structures. It is easy to cause component segregation, coarse structure, and impurity phases. Even defects such as cracks and inclusions. The EDS scanning results from the nickel alloy base plate to the copper alloy showed that the copper and nickel elements showed a uniform transition. The XRD image showed that different diffraction angles (2θ) scanned the diffusion layer interface and no new peaks were obtained [8]; while laser selective melting increased The XRD scanning results of Cu-10Sn, a material made of tin bronze, show the existence of an undefined new peak (new phase) [9]. Laser additive manufacturing involves physical melting, chemical metallurgy and other changes, which will produce compounds or new phases, which will have a great impact on the microstructure and mechanical properties.

Copper alloy wire and 304 stainless steel wire on 304 stainless steel plate electronics In the beam additive manufacturing specimen, the α phase first moves away from the electron beam spot. precipitates in the liquid phase and is distributed in the 1 Layers of molten copper alloy form blocks , and the distribution of iron in the first layer is very uneven. When cladding the second layer of copper When alloying, the iron in the first layer is heated and melted, so there is α phase separation dispersed into the ε phase, and the remaining α phase is distributed at the interface between layer 1 and layer 2 at , as the number of layers increases, the α phase becomes finer and the number becomes smaller and smaller. The less. As the temperature decreases, the Fe element in the copper alloy The solubility of gold decreases until finally Fe atoms only accumulate in certain suitable crystal face, grows into the dendritic α phase; before solid solution, some The liquid iron aggregates and is suspended in the molten pool. Due to the rapid cooling rate, it forms In the spherical structure, the solubility of Cu atoms in Fe decreases as the temperature decreases, so Cu precipitates in the spherical structure. Very similar to electron beam welding Similarly, cracks appear at the copper/stainless steel interface [17].

Copper alloy powder and high-density polyethylene powder are mixed to make circuits Channels have great potential for manufacturing small electronic devices. Gs-3/ 7-15-120 (Gaussian beam-single channel scan-3/7 Copper alloy powder/HDPEEnergy input 15 W scanning speed 120 mm/s) Gaussian beam characteristic energy Concentrated in the middle, approximated by 1/e2, therefore, the specimen is viewed from the top It is divided into two parts, one is the central melting part, and the other is the surrounding heat-affected zone. SEM images observed that the central HDPE is easily melted, even due to evaporation. becomes thinner, or forms a nodular structure with unmelted copper powder, "HDPE" can be clearly seen on the surface. Line";Gs-6/4-20-120 middle The core area can form a dendritic structure and is well formed. Gs-pureCu20-120 Copper alloy powder appears sequentially from the center to the edge of the conductive track From full melting to incomplete melting, if pure copper alloy powder cannot be obtained The HDPE support has very low connection strength and is not suitable for 6/4 copper alloys. Gold powder/HDPE solution, Gs-6/4-20-120 and Gr-6/4-20-120 (r is raster scan) In contrast, the energy density distribution of the laser Gaussian beam is different. Uniform, single-pass scanning melt width is small, and can only increase input energy and reduce scanning speed, but this can easily cause the resistivity to increase. raster scan The energy distribution is uniform and the scanning width is large. The resistivity decreases [11].

Cu-Cr powder hybrid laser additive manufacturing, in 100 μm microscopic In the metallographic structure, Cr Using unmelted powder particles in a copper alloy matrix Widely distributed in the medium, micron-scale solid solution precipitation was found under a higher magnification microscope. material, which is caused by the higher cooling rate. Compared with traditional plus It adopts artificial technology and does not produce precipitates [12]. Further research on Cu -Cr-Zr-Ti alloy Gold powder is used for laser additive manufacturing, and the surface size is 5~20 μm. holes, the sample density is about 97.9%, along the additive manufacturing method direction, the grains are elongated, depending on the heat dissipation direction of the SLM processing process, the grain size is about 30~250 μm, and there is an obvious layer interface. After heat treatment, the grain direction remains unchanged and grows seriously, reaching 40~450 μm [13].

Arc additive manufacturing of mild steel and silicon bronze bimetallic structural specimens Obviously it is different from the laser selective melting process. The length of this sample The size depends on the distance the wire travels, while the width depends on the welding Parameters (welding current, welding speed), welding speed, welding current The larger the value, the width of the sample increases, and the height of each layer first increases and then decreases; EDS shows that Fe, Cu and a small amount of Si exist in the bimetallic structure area; The Fe-Cu binary phase diagram shows that there are no brittle metal compounds in this region, The Fe-rich region forms α phase, and the Cu-rich region forms ε phase [21]. arc heating The source has high additive manufacturing efficiency, large heat input and Gaussian distribution of heat. The characteristics of cloth, but the arc is difficult to control and precision forming. In large components There is a future in additive manufacturing.

Copper alloy additive manufacturing will produce deficiencies such as pores, cracks, precipitated phases, and uneven chemical composition. These deficiencies greatly affect the mechanical properties of the specimen. at the same time, Research on optimizing the process or improving the quality of the original powder has become a hot spot in the research of additive manufacturing technology for other materials. However, copper alloy additive manufacturing is relatively insufficient in these two aspects. Moreover, the surface roughness of copper alloy additive manufacturing is high. It is extremely difficult for one-time additive manufacturing to meet product requirements. Currently, Yang et al. [24] in the United States use Cu_2O powder as a material and additively manufacture samples with low surface roughness through sintering. The effect is significant, and NASA in the United States It does a better job in controlling the surface roughness of additive manufacturing.

2.2 Mechanical Properties of Additively Manufactured Copper alloys

Cu-Cr-Zr-Ti After the alloy powder laser additive manufacturing sample is heat treated, the tensile specimen is intercepted along the vertical additive manufacturing direction and the parallel additive manufacturing direction. The results are shown in Table 2 [13].

Table 2 Mechanical properties of Cu-Cr-Zr-Ti SLM specimen after heat treatment[13]

Specimen type	Tensile strength/MPa 20 °C	600 °C	800 °C	Elongation/% 20 °C	600 °C	800 °C
Vertical additive manufacturing direction	195.1~198.0	69.5~86.2	31.3~33.3	10.8~11.7	4.4~5.7	6.3~12.0
Parallel additive manufacturing direction	210.0~211.0	82.2~82.3	41.2~46.6	13.1~15.8	4.2~7.7	7.8~12.1
Hot rolling-heat treatment	249	107		40	6	

Tin bronze powder laser selective melting additive manufacturing, casting tin bronze Tensile test comparison of copper and SLM specimens, tin green casting The strength of copper is significantly lower than that of tin bronze specimens made by SLM. Cast tin bronze The yield strength of copper is 120 MPa and the tensile strength is 180 MPa; SLM The yield strength of the sample is 220 MPa and the tensile strength is 420 MPa[9]. Copper alloys prepared by traditional casting processes have lower performance than SLM. Double gold The metal structure achieves uniform transition between copper and nickel alloys, and the microhardness in the transition area is The change is smooth and uniform; while the direct cladding copper alloy sample changes at 0.06 mm. Realize the change from 100% copper alloy side to 100% nickel alloy side, and the hardness exists Jump change: (1.38±0.04) GPa to (2.93±0.06) GPa. nickel A high hardness value (2.93±0.06) GPa appears on the alloy side, while the nickel alloy plate The hardness is 2.59 GPa, and the highest hardness occurs in the heat-affected zone [8].

The structure and properties depend on the melting and solidification process of alloy powder. Therefore, only by effectively controlling the additive manufacturing process parameters and manufacturing process can good structure and properties be obtained.

3 CONCLUSION

Domestic and foreign research on copper alloy additive manufacturing is in its infancy, which is manifested in the fact that there are few types of copper alloy raw materials for additive manufacturing, the additive manufacturing process methods are concentrated on laser/electron beam additive manufacturing technology, and the processing process optimization is insufficient and it is difficult to control copper alloy additive manufacturing. The density and porosity during the process have become key factors restricting the development of copper alloy additive manufacturing.

1) There are very few types of copper alloy materials used in copper alloy additive manufacturing, including pure copper, silicon bronze, tin bronze, Cu-Cr series, nickel brass., and the types of copper alloys involved are limited.

2) The research on optimization of copper alloy additive manufacturing process is not in-depth enough. In the test, there is a problem that the density of the prepared samples is low, only part of the density is high, and it is difficult to achieve 100% density. The prepared samples have a certain porosity, and the grain structures obtained by different heat sources are quite different. , has a significant impact on mechanical properties. In the copper alloy additive manufacturing process, issues such as avoiding the introduction and reduction of impurities and the optimization of the heat treatment process for subsequent structural refinement and composition homogenization need to be further studied.

3) The control methods used in copper alloy additive manufacturing technology need to be improved. Currently, there is no numerical simulation research on copper alloy additive manufacturing technology, and there is no relevant research on the relationship between melt pool temperature changes and additive quality. How to control There are also very few studies on the cooling rate of the molten pool and the temperature gradient between each layer. The molten pool temperature and the cooling rate of the molten pool are the core of a series of issues affecting pores, cracks, grain size, microstructure, solid solution precipitation. in additive manufacturing. , Therefore, studying temperature field changes and achieving temperature field control is a major improvement in copper alloy additive manufacturing technology. It can not only solve the problems of cracks and porosity, but also control the grain size well and obtain better results. The microstructure, good mechanical properties, and other specific properties of copper alloys are crucial to improving product performance and quality.

4) The subsequent processing and manufacturing of copper alloy additive manufacturing formed parts is also the scope of copper alloy additive manufacturing technology research. Surface roughness and step effect It should be the remarkable characteristics of copper alloy additive manufacturing in surface forming. point. Among them, rough surface is not conducive to corrosion resistance. There are two ways to solve this problem. Methods: One is to find other processes that can solve the problem of surface roughness. method to effectively control surface roughness; the second is to adopt subsequent finishing, but this will increase the processing cycle, and for complex shapes and precision requirements The requirements for higher parts are extremely high.

5) The process method of copper alloy melting additive manufacturing has shortcomings, and it is necessary to find suitable solid phase additive manufacturing technology to assist. Currently, the methods that can be used for solid-phase additives include friction stir, ultrasonic., and there are very few studies involved in this area, which has certain potential.

With further in-depth research, as well as equipment technology, control technology With the continuous development of technology, it is necessary to develop copper alloy additives with different process methods. manufacturing, optimizing process methods to ensure product quality and precision, and To make up for the shortcomings of traditional manufacturing such as low flexibility, difficulty in small batch production, long processing cycle, high energy consumption, and high pollution, copper alloy additive manufacturing technology is directly There must be a breakthrough in applications in the field of manufacturing and forming.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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