Research of surface quality of structural components made using additive technology of electric arc welding

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Abstract. A brief analysis of the existing methods of additive technologies with reference to the aviation industry is carried out. The prospects of this direction are shown taking into account the possibility of production of aircraft parts on the principle of "bottom-up". The results of researches of additive technology of electric arc surfaced in carbon dioxide of complex parts are presented. In the course of the carried out studies technological peculiarities of the technology connected with the parameters of welding arc, melting of cladding wire have been found out. Arc current has the greatest influence on the appearance of the molding. The wire feed rate affects the height of the welded roll. It is shown that the stability of the welded rolls formation depends on the modes of metal transfer, which depend on the conditions of wire feeding and insertion into the melt bath.

1. Introduction

At present, the aircraft's gliders are mainly made up of monolithic components. Stringers, spars and bulkheads can be included in this category. After milling, they are assembled and connected to the aircraft shells. It should be noted that most of the metal parts are produced either by casting or by so-called "subtraction of excess", when everything that is not needed is removed from the cast part by machining. In this case, the share of material use is at best 50%, and in some types of processing is not more than 20-30%, with the aim of increasing productivity in the conditions of aircraft production tend to the maximum possible speed of milling parts. However, the conditions necessary to achieve this (high feed rate, high cutting depth) during milling imply high cutting forces, which in turn cause undesirable deformations of the workpiece or vibrations in areas (thin walls and shelves) where stiffness is insufficient. These static and dynamic problems often lead to geometric inaccuracies, high roughness and possible damage to the machine spindle.

Additive technologies (hereinafter referred to as AT) are a promising way of producing complex configuration parts [1-4]. They are based not on the "readout-treatment" of the material, but on its addition - layer-by-layer expansion of the material in order to create an object on the basis of an electronic three-dimensional model. These technologies make it possible to use almost the same amount of material that will remain in the finished part in the production process, which increases the coefficient of use of the material and makes it possible to produce parts that cannot be obtained either by casting or machining, for example, with internal cavities with complex shapes. AT are universal, flexible and easily customizable. Materials for manufacturing various parts of machine parts and units can be of different types. These include metal, ceramic and polymeric materials, as well as combinations of composite, hybrid or functionally graded materials (FGMs). The leader in the application of additive technologies in Russia is the Federal State Unitary Enterprise "All-Russian Research Institute of Aviation Materials (VIAM)[2-4], which has significant experience in the field of preparation and production of materials.
for AT. Significant results have been achieved in MSTU named after Bauman, the Samara State Aerospace University named after Academician S.P. Korolev and the Center of Additive Technologies FSUE "NAMI". Abroad, DirectLightFabrication (DLF) laser technologies developed at the Los Alamos National Laboratory, Los Alamos, New Mexico [5,6] and LaserEngineeredNetShaping (LENS ™) have been developed at the Sandia National Laboratory, Albuquerque, New Mexico [7,8]. Both processes provide a continuous supply of powder to the focal area of the laser, where the powder melts and hardens again in the "trace" of the molten bath when the laser beam scans the part. These processes have proven to be suitable for parts made from virtually any material, with high mechanical properties.

The most interesting and effective technologies of metal parts manufacturing by methods of layer-by-layer material application with reference to aviation industry are the following: WAAM (GMAW, PAW, CMT), DMD, LBDMD, EBAM[9].

WAAM – (WireArcAdditiveManufacturing) is one of the additive technologies that uses wire as a surfacing material [10-13].

Various research groups are working to improve wire-arc additive technologies such as GMAW, GTAW and plasma arc welding (PAW)[14-16].

GMAW – is a type of welding called MIG/MAG (inert gas melting arc welding), which involves the automatic supply of a continuous solid melting electrode in a shielding gas atmosphere.

Plasma arc welding (PAW) is a modification of gas-electric tungsten electrode welding (GTAW).

CMT-welding is a MIG/MAG process which has a special type of material drop removal[17]. It allows to apply CMT-process where before technologies of MIG/MAG-welding either were not applied, or it was extremely difficult to apply.

CMT stands for ColdMetalTransfer, i.e. the process allows for "cold" metal transfer when welding or soldering [17].

EBAM cladding technology is based on electron-beam melting of metal wire. Cladding is carried out in a high vacuum, which allows to achieve high density and uniformity of the product, as well as to work with a variety of metals and alloys: titanium, tungsten, nickel alloys, stainless steel, tantalum, niobium, etc. EBAM is currently the only technology that provides sufficient strength characteristics of final products for their use in power structures. Sciaky is engaged in the production of EBAM components for Boeing. The main consumers of additive technologies specializing in metal surfacing are the aerospace, automotive and electrical industries. A company such as TWI LTD uses DMD technology to produce various components for Airbus and Messier-Dowty. Most of the products are manufactured by this company using DMD technology, including turbine housings, cooling elements, engine cylinders, etc. Among other companies that succeed in applying DMD technology, there are DMGMori, Optomec, CNC, Insstek. This technology is also widely used for high-speed prototyping, repair of parts, such as turbine blades, spraying thin layers of material. One of the main advantages of this technology is a high degree of detail and the possibility of creating thin-walled elements (0.1-5.0 mm), such as antennas or various elements of electrical circuits. Besides, the details constructed on this technology, practically do not require the subsequent processing.

Depending on the energy source used in the deposition process for the implementation of the AT metallic components can be mainly divided into three groups: laser-based, electron-beam-based and arc welding-based. The laser as a heating source forms a high positioning accuracy, but has a very low energy efficiency. The electron-beam AT has higher energy efficiency indicators, but it is required for the process of media with high vacuum, which limits the application. In comparison with the AT based on laser and electron beam, the AT based on arc welding has high energy efficiency and cladding speed, and the AT arc welding equipment is more economical than laser and electron beam equipment.

The goal of this research is to study the conditions for obtaining high-quality surfaces of complex shaped parts by means of additive technology of arc welding in shielding gases.

2. Materials and research methods

The energy source chosen for the AT process under study is an electric arc with a melting electrode (GTAW), due to its low cost, absence of the need for a vacuum chamber, its ability to apply a large
volume of surfacing and a much higher speed on the float. The GTAW process can be combined with industrial welding robots and multi-sensor control systems to achieve high precision arc positioning.

Fig. 1 shows the scheme of experimental installation developed for additive production with the use of semi-automatic solid wire surfacing in carbon dioxide. The experimental unit includes an industrial power source, a wire feed mechanism, a carbon dioxide cylinder, a work table and a working chamber. These dimensions are set from the initial parameters of the welding bath and then the rolls overlap each other. Qualitative formation of metal layers is determined by the thermal power of the arc, the rate of cladding, the temperature between the passages and the properties of the material.

In this study, Sv-08G2S wire with a diameter of 1.2 mm was used. Additionally, variants with protective gas mixture Ar (95%) and CO2 (5%) with a flow rate of 18 l/min were considered. The rollers were melted onto a 150×100×10mm plate. Each wall of the part of the welded square consisted of eight layers. Preheating was not carried out. The time between application of each layer did not exceed 1 minute. Fig. 2 shows a complex shaped product obtained with the help of the described surfacing technology.

3. Research and discussion results
Figure 2 shows a typical surface profile of a complex shaped part made on the basis of GMAW. Part of the fused square has been machined. As shown in Figure 2, the welded surface has an uneven appearance due to the layer height of more than 1 mm during the application of many welded layers. In general, the surface quality of the welded parts has a significant impact on the amount of metals to be processed during the subsequent finishing process.

Figure 1. Schematic diagram of an experimental installation developed for the additive production of wire arcs and schematic representation of surfacing
Figure 2. Additive technology of semi-automatic technology of cladding in CO2 to obtain a complex part shape

Fully dense material without defects such as pores, shells, or irregularities is required for most parts to achieve optimum mechanical strength. A defect-free material surface is achieved by optimizing both the energy parameters of the process and the trajectory of the welding torch to maintain a continuous melt bath. The continuity of the welded metal from layer to layer is maintained by melting and remelting into the previous layers when a new layer of metal is added. The melt back depth varies from the fraction of the previous layer to the remelting through several layers, depending on the selected process parameters. On the whole, the experiments showed good formation of welded layers. The results of mechanical processing showed the absence of pores, cracks in the welded wall of the square in Fig. 2. No fusion between the layers was fixed.

Under non-optimal conditions, the formation of microstructure porosity is possible, which is mainly due to the release of gas during solidification and the absence of melting between the layers or adjacent passages of the molten bath. Increasing the capacity of the welding arc, reducing the speed of movement or using thinner layers can help to merge and reduce or eliminate this type of voids. The influence of arc current, cladding speed and heat generation on layer formation was analyzed using a passive vision sensor. Based on the experimental results, the arc current has been found to have the greatest effect on the appearance of the moulding process.

The analysis of the publication on technological issues of additive technologies based on GMAW has shown that the main research is focused on several aspects, such as forming technology, optimization of layer geometry, measurement and control of layer geometry, microstructure mechanical properties, evolution of temperature distribution and residual stresses, etc. There are very few publications related to the quantification of surface roughness after surfacing. In this study, surface roughness is quantified by optical measurements. The quality of the metal on the side of the workpiece is clearly visible, after surfacing and machining. There are no cracks, pores, or fusions. In Fig. 3 the surfaces marked with arrows A and B are obtained after multi-layer cladding and subsequent milling. Surfaces F, E milled areas of the base metal after traditional casting. Measuring the roughness of the welded surface and the metal surface after casting shows that the quality of the welded surface is higher than that of the surface of the casting.
4. Conclusion
In the course of the carried out researches the peculiarities of the electric arc welding technology connected with the parameters of the welding arc and the character of melting of the surfacing wire were established.

![Image of welded roll]

Figure 3. Roughness measurement of the vertical wall surface A after surfacing and casting surface Fc by subsequent milling

Arc current has the greatest influence on the appearance of the part. The wire feed rate affects the height of the welded roll. It is established that the stability of the welded rolls formation depends on the

![Graph of roughness measurement]
modes of metal transfer, which depend on the conditions of wire feeding and insertion into the melt bath. It was found that the wire can reach the molten bath before it is completely melted by the arc. In this case, the heat from the molten bath can help melt the wire, but the melting rate will slow down. The direction of feeding can only influence the stability of the process if the molten bath facilitates the melting of the wire, which is a sensitive condition for operation regardless of the direction of wire feeding. The reason for this is the resistance from the arc, which affects the droplets while they still grow and do not enter the bath. However, the size of the drips at which this happens depends on whether a concave or convex melt bath is used. Measurements of the roughness of the welded metal after machining compared to cast metal show low values of parameters, which indicates a high quality of the surface obtained.

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