# Finite Element Modeling and Visualization of Additive Ring Growing by 3DMP Method

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**Abstract.** The aim of the work is to obtain a finite element model of the additive growing process in the general case of a complex-shaped product using the 3DMP (3D Metal Print) method of wire deposition / surfacing by gas metal arc welding, visualization of the forming temperature fields. The problem is solved using the example of an elementary ring by creating a scalable model in the Ansys software package. The stages of creating a finite element model as well as the results of its approbation in the analysis of temperatures are given. The model visualizes the nature of the influence of the deposition / surfacing parameters on the temperature fields that are formed and dynamically change with the movement of the wire feedstock. In this case, the conditions of additive free shaping of a closed-form product are of no small importance. It becomes possible to visually assess the degree of heating and the volume of heated metal in the hazardous area, proceed further to the calculation of stress and strain fields in the grown product, and choose the correct technological parameters of the process. The obtained visual information makes it possible to perform a qualitative and quantitative assessment of the additive shaping result, to determine the required intensity of heat removal, which contributes to the grown product quality improvement as a whole.

**Keywords:** Finite Element Model, Visualization, Electric Arc Welding, Wire Deposition / Surfacing, Additive Growing, Process Parameters, Temperature Fields, Ring.

## 1 Introduction

Currently, the most progressive technology for shaping parts in the manufacture of products in the aerospace and automotive industries, as well as general mechanical engineering, is additive growing. The average annual growth rates of the world market of additive technologies (AT) are: in 2007 ... 2013 - 19%, and in 2013 ... 2021 - up to 32% (forecast by Wohler Associates).

A fairly large number of ATs have been developed, among which the most common are powder. However, powder additive technologies SLM / EBM / DED and LMD require high capital and material costs and are characterized by a low rate of product growth (as a rule, from 5 to 20 ... 35; maximum - up to 120 cm3 / hour), have a high cost per hour. EBAM technology is distinguished by a high synthesis productivity (up to 900 cm3 / h) and wider possibilities for the size of parts, but it is also difficult to compete with traditional technologies in terms of economic indicators due to the need to create vacuum and the high cost of the equipment used.

With the advent of 3DMP technology, we can speak about the creation of AT-competitive with traditional technologies in terms of economic efficiency, due to high productivity (up to 600 cm3 / h) and the absence of restrictions on the size of the grown products. 3DMP (3D Metal Print) is a technology for the deposition / surfacing of wire by the method of electric arc welding (gas metal arc welding, GMA welding, GMAW). Unlike well-known processes of manual, semi- or automatic welding (GMAW) in inert gas (metal inert gas, MIG) or active gas (metal active gas, MAG), 3DMP technology is a fully automated process using CAD / CAM data arrays.

Despite the fact that 3DMP technology uses widespread arc welding, its implementation has to solve specific problems of shaping that are not inherent in traditional welding processes [1-4]. For example, it is necessary to solve the issues of accurate positioning of wire feedstock, dosed wire feed, interconnected not only with the modes of electric arc surfacing, but also with the coordinates of the feedstock, solving the problem of dynamic distribution of heat fluxes, which largely determines both the stressed state of the grown product and the accuracy of the shape of the grown product and the size of the defective layer to be subsequently removed by mechanical means. Modeling and visualization of the processes accompanying the additive growth of a product can provide invaluable assistance in making technological decisions [5-9].

The overwhelming majority of well-known software systems are designed to calculate heat fluxes, stress and strain fields in a completely finished product. The most difficult and least studied is the modeling of rapidly flowing technological processes in which the studied parameters are constantly and continuously changing.

## 2 Finite element modeling and visualization of additive ring growing by 3DMP method

The problem of obtaining a finite element model of the process of additive growth of a product using the 3D Metal Print method of wire surfacing by electric arc welding was solved using the example of an elementary ring. This scalable model was created in the Ansys software package, which is the world leader in the field of modern engineering analysis.

The model was developed in three stages (Fig. 1). At the first stage, work was carried out related to the creation of the geometry of the deposited ring and the base plate it was placed on. To do this, in the Workbench, from the Toolbox section, the Geometry module was transferred to the Project Schematic window. A ring 22.5 mm high with an inner and outer diameters of 100 and 109.6 mm, respectively was created in it. Under the bottom end of the ring, using the "Sketch" function, a base plate 10 mm thick and side dimensions 120 * 120 mm was created (Fig. 2, a). Since the 3DMP technology, by virtue of its peculiarities, implies a phased growing of products, the created ring was divided in the transverse direction of the axis into nine planes, with a distance between adjacent of 2.5 mm (Fig. 2, b). Thus, a product consisting of nine layers, 2.5 mm thick, placed one above the other was obtained. Further, the geometry of the product, in the direction of the axis, was divided into 200 sectors (Fig. 2, c). Thus, the size of one sector was 1.75 * 4.8 * 2.5 mm, which is the volume that arc welding can weld, moving the feedstock wire in one second. All geometric elements, the ring was split into, were combined into one component with the assignment of the "Share" type, which ensured the formation of a single finite element mesh for the entire product.

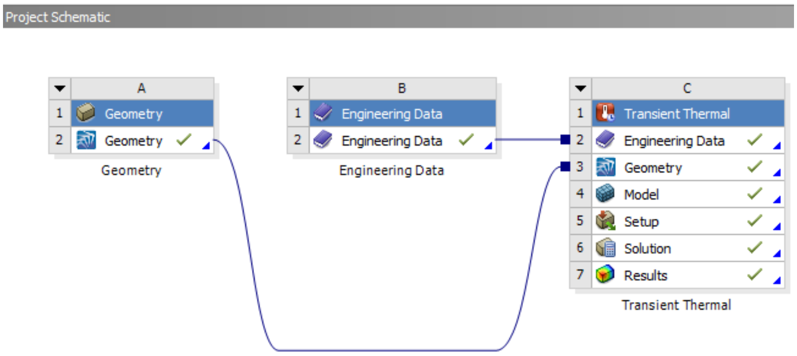


**Fig. 1.** Stages of creating a finite element model.

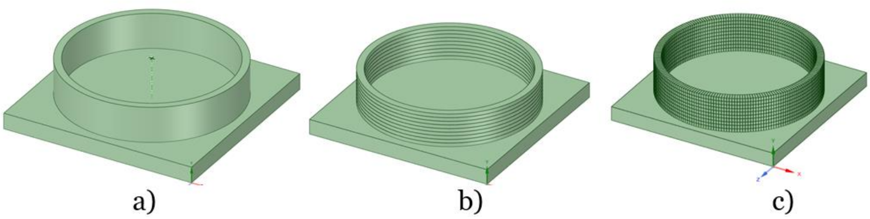


**Fig. 2.** Stages of creating model geometry.

At the second stage, a model of the material used was created. For this, the “Engineering Data” module was moved to the “Project Schematic” section. It specified the physical and mechanical properties of the material used, such as thermal expansion coefficient, density, Young's modulus, Punson's coefficient, thermal conductivity, yield stress, strength, specific heat, tangential modulus, etc. Some physical and mechanical properties were set depending on temperature ... The values of the physical and mechanical properties of the material used were partially taken from the reference literature, partially obtained as a result of corresponding experimental studies.

In the third stage, the additive growing process (3DMP) was modeled. For this, the Transient Thermal module was added to the “Project Schematic”. The preparation of the module for the calculation began with importing the created material and assigning it to the ring elements. The base plate material was assigned the type - structural steel. It was selected from the database of materials of the program. Next, in the "Connectoins" section, a contact area was created between the elements of the bottom end of the ring and the surface of the base plate. The contacting elements were assigned the "Bonded" type. Then, using the "Mesh" function in the ring and the base plate, a finite element mesh was built.

Arc weld surfacing was simulated using the “Internal Heat Generation” function, which internally heats a selected volume of material. This ensures a volumetric temperature distribution. The "Internal Heat Generation" function has a dimension of J / (mm3 * s) and is applied to the volume of one selected ring sector (1.75 * 4.8 * 2.5 mm). The value of the heat flux set by the “Internal Heat Generation” function was determined according to [10].

To ensure the gradual creation (growth) of the elements of the sectors, the layers of the ring were formed from the "Element Birth and Death" function was used. It makes it possible to suppress (remove from the calculation) all elements of the ring geometry before starting the calculation, except for one sector, which is the place where surfacing starts. This sector was heated by the “Internal Heat Generation” function for one second and was an element of the first calculation step. At the second step, the second sector appeared in the calculation, and then it also heated up for one second, etc. This approach allows simulating the movement of wire feedstock for electric arc welding. In the created model, it moves in a spiral, counterclockwise. Thus, by the end of the calculation, all 1800 sectors that make up the ring will be grown.

The preparation of the model for analysis is completed in the "Analysis Setting" section. It determines the total calculation time and sets the maximum and minimum time steps.

The temperature distributions obtained as a result of modeling the process of additive growth of a product by the 3D Metal Print method of wire surfacing by electric arc welding are shown in Figures 3-6.

Figure 3 shows the distribution of temperature fields in the A-A ring section obtained using the "Temperature - Surface" function set.

Figure 4 shows the dependence of the temperature distribution on the process time, obtained at specific points indicated on the ring surface. Building such dependencies is possible using the "Temperature - Probe" function.

The final distribution of temperature fields in the third, sixth and ninth deposited layers of the ring are shown in Figure 5. These graphs were obtained using the "Temperature - Coordinate System - Surface" function set and represent a horizontal section of the ring with a cutting plane.

Visualization of the formation of temperature fields obtained as a result of modeling allows us to estimate the degree and depth of heating, as well as the volume of intensely heated metal in the hazardous area. The figures show that after growing of 3

... 5 turns, a temperature balance occurs, the heating of the product as a whole occurs slowly and evenly, its temperature, rate and intensity of heat removal depend on the organization of cooling of both the substrate and the product being grown.

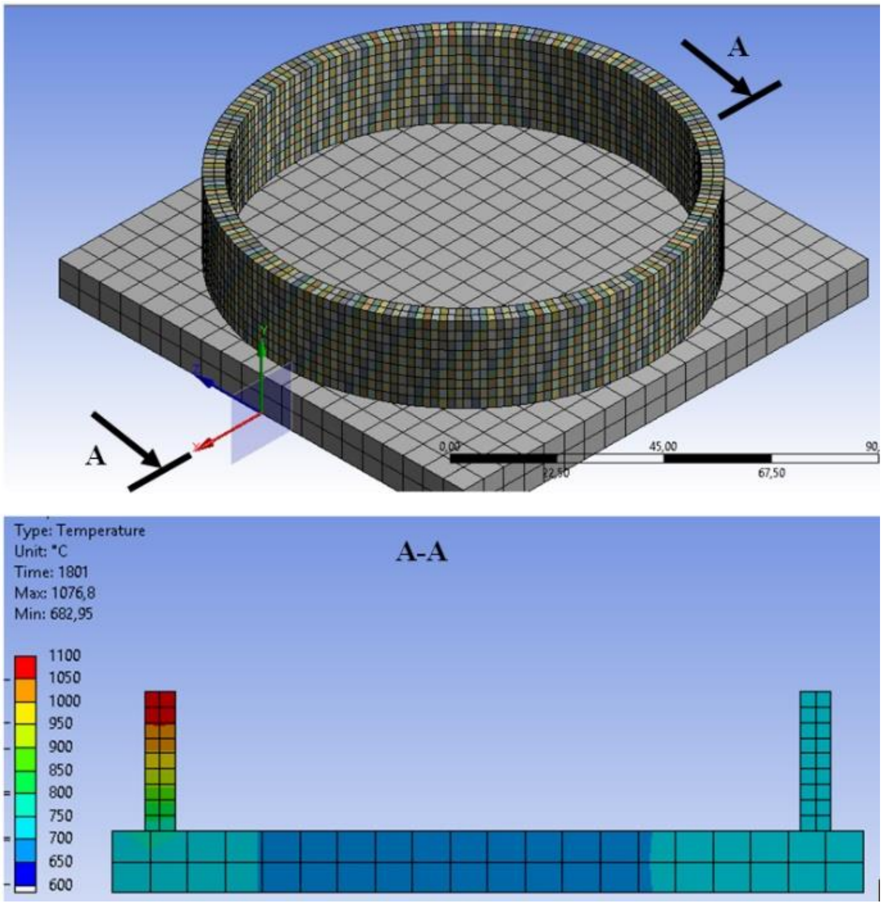


**Fig. 3.** Distribution of temperature fields in A-A ring section.

The results obtained make it possible to proceed in the future to the calculation of the stress and strain fields in the grown product, and to choose the correct technological parameters of the process.

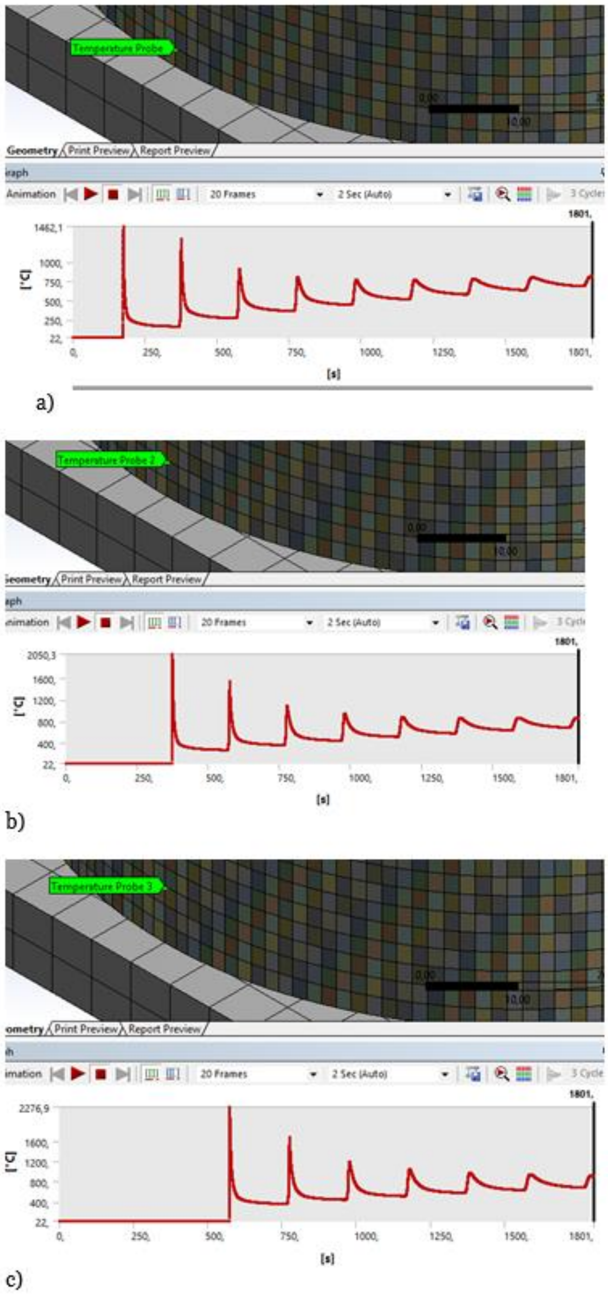


**Fig. 4.** Dependences of the temperature distribution on the process time obtained at specific points indicated on the ring surface.

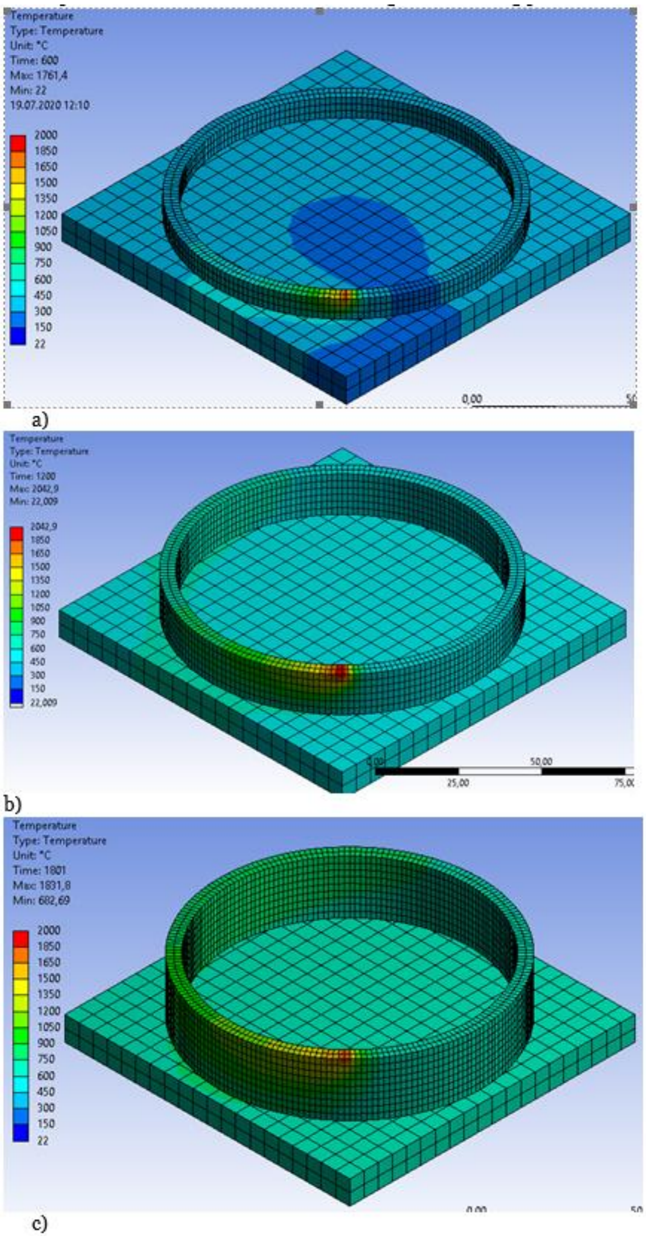


**Fig. 5.** Distribution of temperature fields during ring growing: a) the third layer (at 600 seconds of the process), b) the sixth layer (at 1200 seconds of the process), c) the ninth layer (at 1800 seconds of the process).

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