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MODELING OF WELDING PROCESSES FOR TRANSFERRING TECHNOLOGIES TO EXTRATERRESTRIAL CONDITIONS

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Abstract: The process of computer modeling occupies an increasingly important niche in scientific and technical evolution. Modeling of welding processes provides an opportunity to make preliminary calculations without wasting materials and to avoid rough work. Welding modeling is the latest technology, which is used not only for economically feasible optimization of the process, but also to predict its consequences, including thermal impact and possible deformations in the future during structure operation. Modern software provides a wide range of possibilities, from characterizing the external conditions under which welding takes place, namely: temperature, gravity, pressure, etc. up to highlighting the processes that occur with the material after welding, even after years.

Relatively recently people have begun to experiment with different technological processes in conditions, different from the usual ones, namely Earth. Welding is no exception and is being experimented with from underwater to space. Modeling of such processes is crucial, it doesn't just simplifies the work of welders, but also saves lives.

With the advent of a new goal - to perform quality welding in space - new challenges have emerged in all areas. The astronaut's suit (spacesuit) should be more adapted to work with molten metals, gloves should be more mobile for the astronaut to perform manipulations, a helmet with the function of protecting the eyes from bright radiation. Creating power generators of a completely new era, not adapted from terrestrial conditions is also a challenge. Pre-flight training of astronauts expands the range of skills and knowledge required. Design and development of new welding machines, taking into account important factors of work - weight, limited size, ease of use, technological versatility (one machine performs several functions), the maximum possible automation, possible work in vacuum and weightlessness. The question of simplicity of adaptation of this or that technology under conditions different from terrestrial remains actual.

Keywords: welding, extraterrestrial conditions, modeling, thermal exposure.

МОДЕЛЮВАННЯ ЗВАРЮВАЛЬНИХ ПРОЦЕСІВ ДЛЯ ЗАСТОСУВАННЯ ТЕХНОЛОГІЙ У ПОЗАЗЕМНИХ УМОВАХ

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Анотація: Процес комп'ютерного моделювання займає все важливішу нішу в науковій і технічній еволюції. Моделювання процесів зварювання надає можливість здійснити попередні розрахунки без витрат матеріалів і уникнути чорнової роботи. Моделювання зварювання є новітньою технологією, яку використовують не тільки для економічно-доцільного розрахунку процесу, але і для прогнозування його наслідків, зокрема термічного впливу та можливих деформацій у майбутньому при експлуатації конструкції. Сучасні програми для розрахунків мають широкий спектр можливостей, від встановлювання характеристики зовнішніх умов при яких відбувається зварювання, а саме: температура, гравітація, тиск і т. д. до висвітлювання процесів, які відбуваються з матеріалом після зварювання, навіть через роки.

Відносно нещодавно люди почали експериментувати з різними технологічними процесами, змінюючи умови, що відрізняються від звичайних — Земних. Зварювання не стало виключенням. Занурювались у воду, або навпаки летіли в космос. Моделювання таких процесів є надважливим, воно не тільки здатне спростити роботу зварювальникам, але і врятувати життя.

З появою нової цілі - виконання якісних зварювальних робіт у космосі - з’явились нові задачі по всіх пересічних сферах. Костюм космонавта (скафандр) повинен стати більш адаптованим під роботи з розплавленими металами, рукавиці більш мобільні для виконання астронавтом маніпуляцій, шолом з функцією захисту очей від яскравого випромінювання. Створення генераторів живлення зовсім нової епохи, а не адаптовані із земних умов. Підготовка космонавтів перед польотом розширює спектр потрібних навичок і знань. Проєктування і розробка нових зварювальних апаратів, враховуючи важливі фактори роботи - вага, обмежені розміри, зручність у використанні, універсальність у роботі (одна машина виконує декілька функцій), максимально можлива автоматизація, можлива робота у вакуумі і невагомості. Актуальним залишається питання простоти адаптації тієї чи іншої технології під умови, відмінні від земних.

Ключові слова: зварювання, позаземні умови, моделювання, термічний вплив.

1 INTRODUCTION

Only 53 years ago (in 1969), Soviet cosmonauts Valery Kubasov and Georgy Shonin performed welding in space for the first time using "Vulkan" system developed by the E.O. Paton Electric Welding Institute. In total, they conducted three experiments — manual metal arc, electric beam and plasma (compressed arc) welding. In 1984 (38 years ago) an extremely important experiment was conducted on welding, cutting, soldering and spraying in open space by Svetlana Savitskaya and Vladimir Janibekov. These experiments launched a new, completely unexplored field of research [1].

Space missions, which are set by modern progressive teams and companies (for example, SpaseX) build an idea of space exploration at a very fast pace. Adapting the growing manipulation of the lunar surface is a matter of time, not simply an opportunity, as it was before. Mankind is currently actively studying the topic of colonization of the planets, which offers great opportunities. Among them are new resources, new conditions for human adaptation, new territories for life, etc.

Modern tools for forecasting and modeling provide researchers with opportunity to assess the problems they will face in certain conditions. In particular, when studying and analyzing welding work in conditions other than Earth's, it is possible to use models to identify problems or, conversely, the benefits using different approaches.

2 STATE OF ART ANALYSIS AND STATEMENT OF THE PROBLEM

Welding is an important and widespread technological process for the production and repair of structures for various purposes. However, most welding processes involve the use of heat sources, so in most cases, when joining metallic materials, we face the effects of the thermal cycle. In particular, thermal exposure leads to the formation of a heat affected zone (HAZ) - the area adjacent to the joint zone, in which due to heating and further cooling changes in structure, mechanical properties, chemical composition are observed [2]. Depending on the technology and technique of welding, thermal exposure leads to the formation of residual deformations and stresses, which also lead to changes in the characteristics of the structural material. Depending on the operating conditions, such changes may even cause local damage and failure of the structure as a whole [3].

In the general case, the thermal effect of the welding process on the structure is determined by technology (welding with or without melting the metal, the formation of the connection gradually along the joint or simultaneously), material (heat capacity, thermal conductivity, melting point, etc.), geometry of parts (shape, mutual location), energy characteristics of the heat source (power, energy density, heat input) and the environment [2]. The environment, in particular, will determine the initial temperature of the parts and the conditions of cooling and heat dissipation from the heating zone. In addition, it will affect the need to apply protection to the welding zone.

It is obvious that when performing welding work in extraterrestrial conditions, the characteristics of the environment will differ at least from the terrestrial ones. In addition, a number of welding methods are gravitationally dependent, so there will be an impact on the technology as such. Therefore, modeling, in particular, thermal welding cycles for conditions other than terrestrial, is a relevant and interesting task.

3 RESEARCH AIM AND OBJECTIVES

The aim of the study is to model and visualize the temperature fields in the welded joint for cases where welding is performed in extraterrestrial conditions.

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The objectives of the study are to determine the parameters for model construction and compare, in particular, the values of the width of the HAZ under different welding conditions.

4 RESULTS

Analysis was performed for welded structures located in three most different conditions, namely: the Earth, Mars and the Moon.

Simulation is carried out using a specialized software environment.

The structure consists of a plate and a pipe (one-sided T-joint). Dimensions of the plate: 150 x 150 mm, thickness 50 mm. Pipe dimensions: outer diameter 400 mm, thickness 20 mm, height 400 mm. The pipe is located on the plate with a shift relative to the point of intersection of the axes of symmetry of the plate, which makes it possible to estimate the temperature effect in more remote areas without increasing the size and, consequently, speeds up calculations.

Simulation was performed for single pass welding without beveled edges and without preheating. The joint is formed in the sector of the pipe between the radii drawn at an angle of 45°.

The material of the parts an analog of 2024-AlCuMg2 alloy (solidus temperature 640°C, liquidus temperature 500°C, latent heat - 0.922 J/kg) [4]. 2024 type alloys, alloyed with copper and magnesium, are one of the most common in the production of aerospace structures [5].

Aluminum alloys for aviation and space use, in particular 2024, are sensitive to heat treatment, the heat affected zone is limited by the isotherm of 200°C [6].

The thermal impact of the process was assessed for the time stamp, which indicates the intermediate result, immediately after the end of welding and at the thirty second after the start of welding, when the introduction of heat into the weld is stopped, but its distribution in parts continues.

The model is built for the case of fusion welding using a heat source of medium density ~ 105 W/cm2 at a temperature of 8000°C. To do this, the model uses the type of welding ARC welding with the following parameters [7]:

- Welding speed - 5 mm/s
- Voltage - 17 V
- Electric current - 100 A

Heat input is 340 J/mm, i.e. is within the values recommended for arc welding of aluminum alloys sensitive to heat treatment [8].

Other parameters of modeling of welding in the conditions of the Earth, the Moon and Mars are given in table 1 (data taken from open sources).

Table 1

Simulation parameters for different conditions

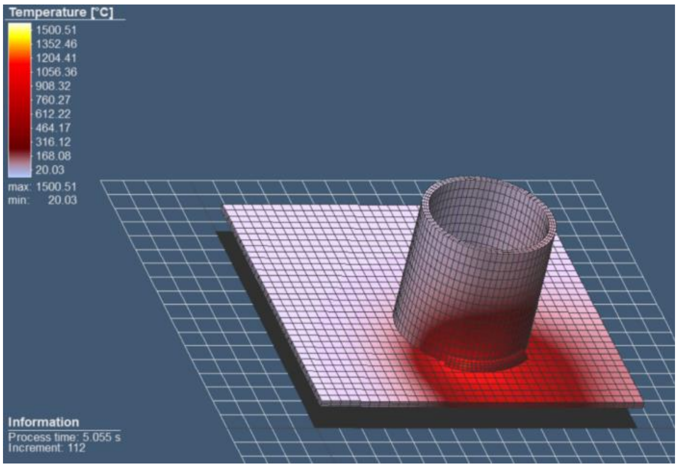
Conditions of welding	Starting temperature, °C	Starting part temperature, °C	Gravity on the structure, $м/с^2$
Earth	+20	+20	9.80665
Mars	-123 (minimal)	-123	3.721
Moon	+116.8 (maximal)	+116.8	1.63444

Models in all cases of the image at zero coefficient of deformation.

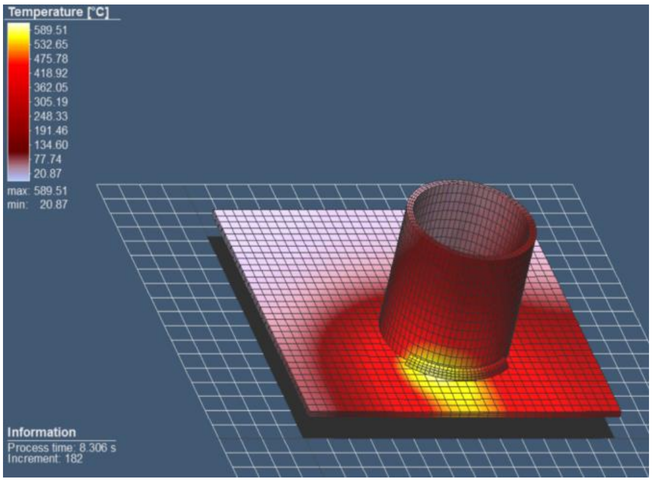
The screenshots show the moments of maximum heating and completion of modeling (state of the structure after 30 seconds from the beginning of the process).

In the upper left corner is a column of temperature fluctuations, and their distribution by color. The color changes depending on the results that are displayed on the model, so for different simulation parameters, the same temperature can be indicated by different colors.

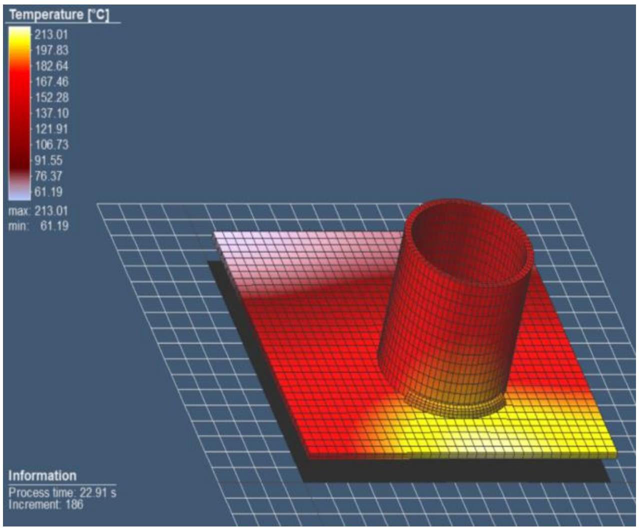
Results of simulation for different conditions are given on Fig.1 - 3.



a

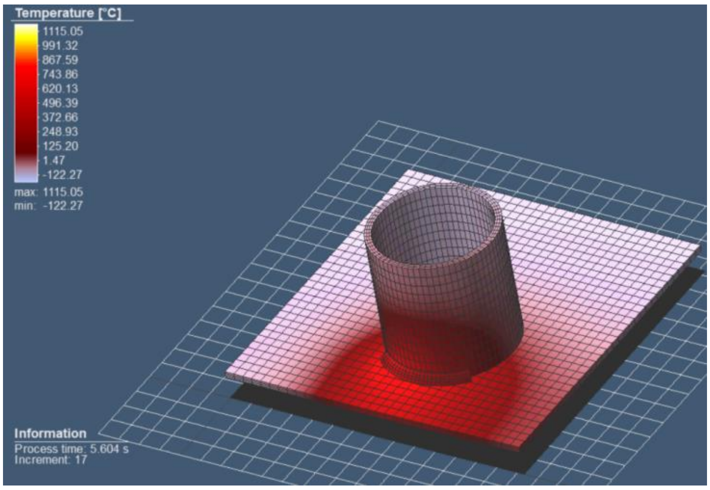


b

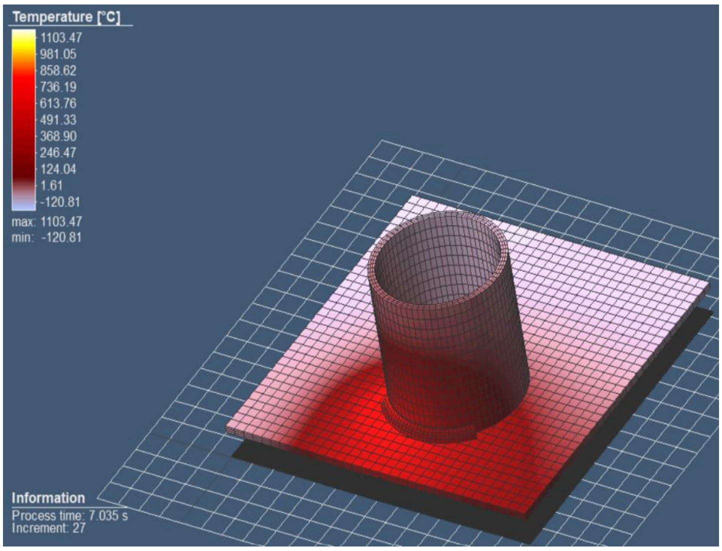


c

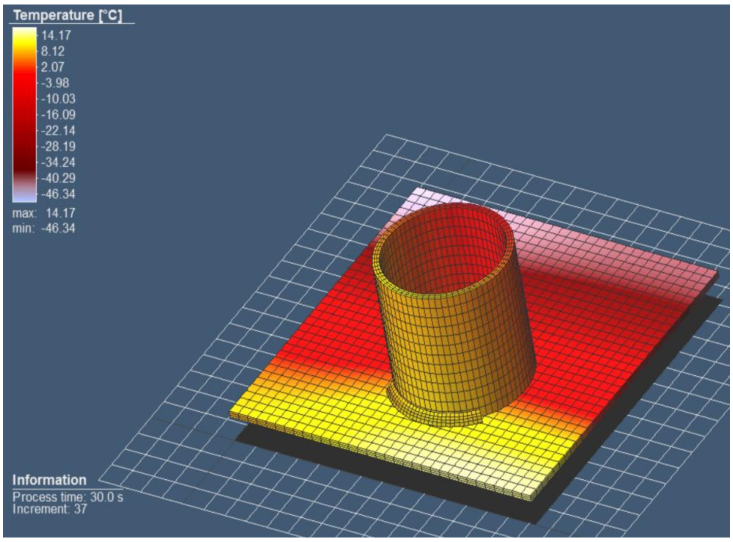
Fig. 1. Modeling of welding in terrestrial conditions: a – 5 s after the beginning of the process; b - completion of the welding process; c – 30 s from the beginning of welding



a

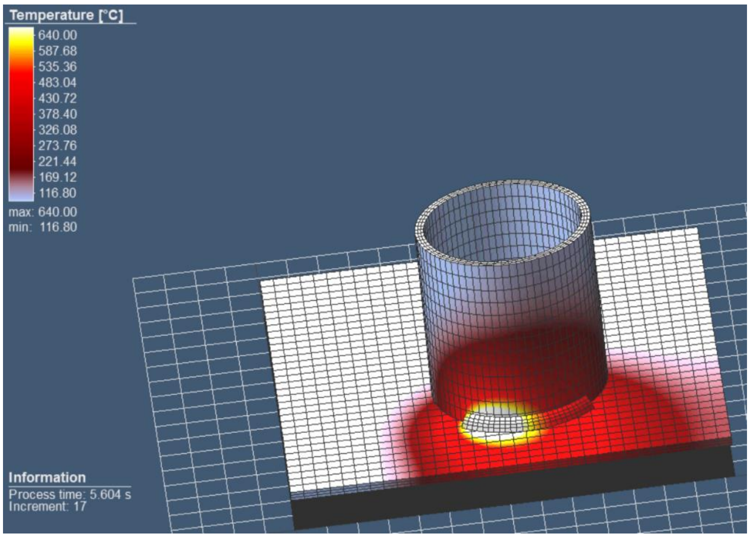


b

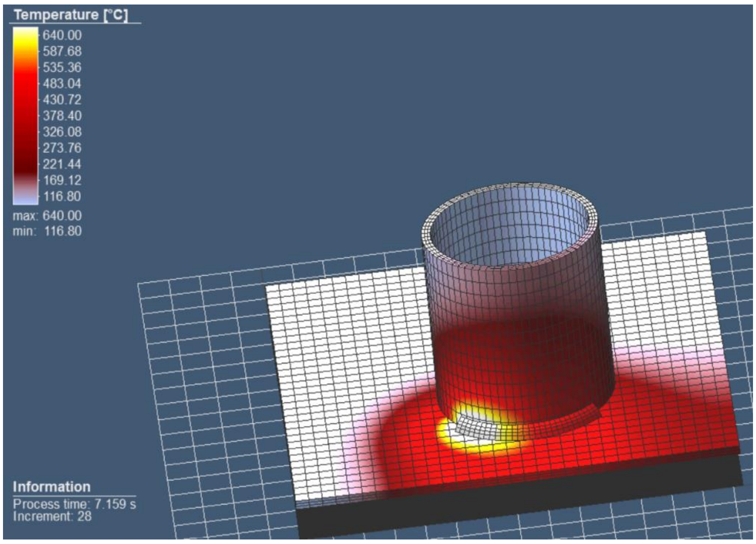


c

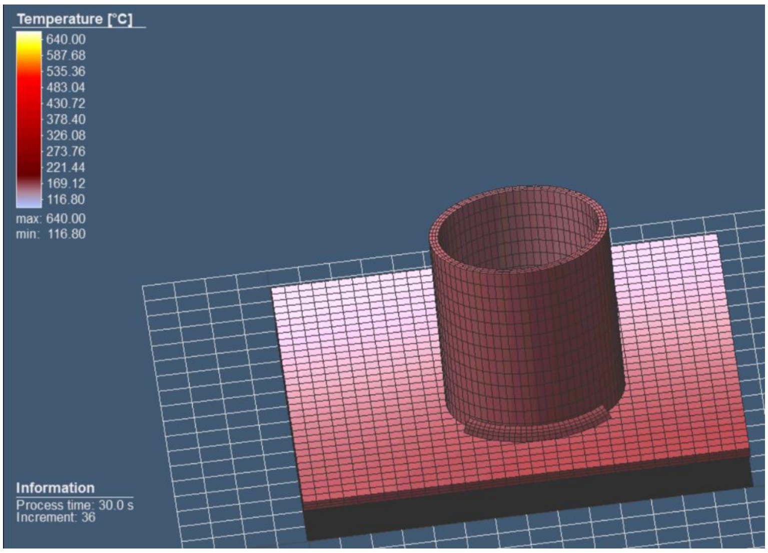
Fig. 2. Modeling of welding in Mars conditions: a – 5 s after the beginning of the process; b - completion of the welding process; c – 30 s from the beginning of welding



a



b



c

Fig. 3. Modeling of welding in Moon conditions: a – 5 s after the beginning of the process; b - completion of the welding process; c – 30 s from the beginning of welding

5 DISCUSSION OF RESULTS

The model for terrestrial conditions shows that after 3 seconds from the start of welding the most active temperature effect occurs in the area of 40x21x20 mm, and after 5 seconds this area expands to 60x21x20 mm. 30 seconds after, the entire surface of the structure, except for the most remote part of the corner with a bisector of 20 mm - was in conditions of adverse temperature effects.

Models for the conditions of Mars and the Moon show a similar nature of heat distribution, but differ significantly in temperature values.

In this simulation it is possible to observe changes in temperature in several processes, namely - heating, welding effects, heat distribution in the structure and the cooling process. Since all three simulations reflect a process that lasts about 7 seconds, it is obvious that further changes in the picture are the process of cooling parts with the simultaneous spread of heat from the hottest zone. At the lowest external temperature (-123ºC - Mars) after 3 seconds the highest temperatures are observed in the area of 42x22x21 mm. After 12 seconds the temperature in the whole structure will rise, but at the same time its most remote edge has a temperature lower by an average of 110ºC. After welding (the time interval is marked as the time after the 7th second), the part of the structure close to the weld has an average temperature of + 14ºC, the average temperature throughout the structure ranges from -30ºC to -3ºC, and the most remote plate angle of 18x42x35 has the smallest influence, its temperature -46.34ºC.

Given the sensitivity of the material to thermal cycles (susceptibility to quenching), it can be predicted that the reproduction of modern technological approaches to its welding will lead to deterioration of performance due to high values of cooling rates. Therefore, it will be advisable to either carry out pre-heating and associated heating, or switch to solid-phase welding technology, in which the temperature of the heat source is lower than the melting point of the metal structure.

For the conditions of the Moon on the third second the maximum temperature influence has a site of 47x15x23 mm. After 12 seconds the whole structure is under the influence of temperature changes, the temperature difference between its most remote edge and the average of the structure is 150ºC. After welding (the time interval is marked as the time after the 7th second) the entire surface of the part was significantly affected, while the area adjacent to the far corner, measuring 20x40x36 mm has an increase in temperature by only 2ºC. Thus, it is possible to transfer modern technological techniques without significant changes.

6 CONCLUSIONS

Modeling of the extraterrestrial welding process has shown that the general patterns of heat distribution from the heat source in the part remain unchanged. At the same time, the dimensions of the zone heated above the temperature threshold and the average temperature of the structure differ significantly. In some cases, it is possible to directly transfer modern technological techniques to extraterrestrial conditions.

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