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A THREE-DIMENSIONAL MODELING OF THE THERMAL FIELD DURING WELDING THERMAL CYCLE

In this paper finite element modeling of welding thermal cycle is studied. The finite element method (FEM) is the dominant discretization technique in structural mechanics. FEM simulations are nowadays useful to predict such things as the weld pool shape for various combinations of process parameters from the temperature distribution plots.

One of the important problems in welding engineering is to construct a mathematical model for the computer simulation of welding process. During the welding process, because of the heat input transferred to the material, heat transmission inside the work-piece and heat exchange with the external environment occur. Numerical simulation of heat manufacturing processes is preferred to analytical methods for modeling in welding technology. In fact as the welding arc interacts with the surface of the work-piece during its passage, very rapid series of heating and cooling cycles are achieved. Therefore it results to be difficult to adopt analytical model technique to investigate about the process. Instead numerical models are suitable to assess the thermal cycles and their relationship with process parameters. Welding was done with different modes to analyze and predict the geometry, the shape of the seam and the depth of weld penetration. For the calculation of the thermal conditions accompanying the process of melting the metal surface, a mathematical model was used, which is based on the differential equation of heat conduction in a three-dimensional Cartesian coordinate system.

In this work the simulation of the thermal field during the TIG welding process of VT23 titanium alloy joint is presented. The thermal analysis is concentrated on the prediction of the heat transfer in the weld. A distributed volume heat-source was validated on the basis of the comparison with the experimental specimen cross section. The temperature distribution in the overall weldment, the shape and size of the fusion zone, heat affected zone, the maximum cooling speeds in different parts of HAZ were predicted. Based on quite satisfactory results, this work shows, that FE simulations can enable faster, less costly, and more optimized product development, as well as examinations of product performance that would not be possible even using very detailed prototypes.

Key words: finite element method, mathematical modeling, thermal fields, welding.

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ТРИВИМІРНЕ МОДЕЛЮВАННЯ ТЕПЛОВОГО ПОЛЯ ПІД ЧАС ТЕРМІЧНОГО ЦИКЛУ ЗВАРЮВАННЯ

У даній роботі досліджується скінченно-елементне моделювання термічного циклу зварювання. Метод скінченних елементів (МСЕ) є домінуючим методом дискретизації в будівельній механіці. Моделювання МСЕ сьогодні корисне для прогнозування таких речей, як форма зварювальної ванни для різних комбінацій параметрів процесу на основі графіків розподілу температури.

Однією з важливих проблем техніки зварювання є побудова математичної моделі для комп’ютерного моделювання процесу зварювання. У процесі зварювання за рахунок надходження тепла до матеріалу відбувається передача тепла всередину заготовки і теплообмін із зовнішнім середовищем. Чисельному моделюванню теплових виробничих процесів надають перевагу перед аналітичними методами моделювання в технології зварювання. Фактично, оскільки зварювальна дуга взаємодіє з поверхнею заготовки під час її проходження, досягається дуже швидка серія циклів нагрівання та охолодження. Тому важко прийняти техніку аналітичної моделі для дослідження процесу. Натомість чисельні моделі придатні для оцінки термічних циклів та їх зв’язку з параметрами процесу. Зварювання проводилося в різних режимах для аналізу та прогнозування геометрії, форми шва та глибини проплавлення шва. Для розрахунку теплових умов, що супроводжують процес плавлення поверхні металу, використано математичну модель, яка базується на диференціальному рівнянні теплопровідності в тривимірній декартовій системі координат.

У цій роботі представлено моделювання теплового поля під час процесу TIG зварювання з’єднання титанового сплаву ВТ23. Термічний аналіз зосереджений на прогнозуванні теплопередачі у зварному шві. Розподілене об’ємне джерело тепла підтверджено на основі порівняння з поперечним перерізом експериментального зразка. Прогнозовано розподіл температури в зварному виробі загалом, форму та розмір зони проплавлення, зони теплового впливу, максимальні швидкості охолодження в різних частинах ЗТВ. Базуючись на досить задовільних результатах, ця робота показує, що моделювання FE може забезпечити швидшу, менш дорогу та більш оптимізовану розробку продукту, а також перевірити продуктивність продукту, що було б неможливо навіть за допомогою дуже детальних прототипів.

Ключові слова: метод скінченних елементів, математичне моделювання, теплові поля, зварювання.

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Introduction

The finite element method (FEM) is the dominant discretization technique in structural mechanics. The basic concept in the physical interpretation of the FEM is the subdivision of the mathematical model into disjoint (non-overlapping) components of simple geometry called finite elements or elements for short. The response of each element is expressed in terms of a finite number of degrees of freedom characterized as the value of an unknown function, or functions, at a set of nodal points. The response of the mathematical model is then considered to be approximated by that of the discrete model obtained by connecting or assembling the collection of all elements. The disconnection-assembly concept occurs naturally when examining many artificial and natural systems. For example, it is easy to visualize an engine, bridge, building, airplane, or skeleton as fabricated from simpler components. Furthermore, FEM has become a powerful tool for the numerical solution of a wide range of engineering problems. Applications range from deformation and stress analysis of automotive, aircraft, building, and bridge structures to field analysis of heat flux, fluid flow, magnetic flux, seepage, and other flow problems [1, 2].

Objective of the research

For this study high-strength titanium alloys were chosen. The use of titanium alloys has been expanding in the aerospace, power-generation, medical, chemical plants, and marine applications due to their superior mechanical and corrosion properties. This is due to several unarguable properties such as excellent corrosion resistance, bio-compatibility, good temperature performance and high specific mechanical resistance that made these alloys almost irreplaceable in many applications. Joining processes play a fundamental role in the productive scope of many industries and many welding techniques have been studied and developed to process this alloy. The main welding process for titanium alloys is gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding [3-5].

One of the important problems in welding engineering is to construct a mathematical model for the computer simulation of welding process. During the welding process, because of the heat input transferred to the material, heat transmission inside the work-piece and heat exchange with the external environment occur (Fig. 1). Numerical simulation of heat manufacturing processes is preferred to analytical methods for modeling in welding technology. In fact as the welding arc interacts with the surface of the work-piece during its passage, very rapid series of heating and cooling cycles are achieved. Therefore it results to be difficult to adopt analytical model technique to investigate about the process. Instead numerical models are suitable to assess the thermal cycles and their relationship with process parameters [6-11].

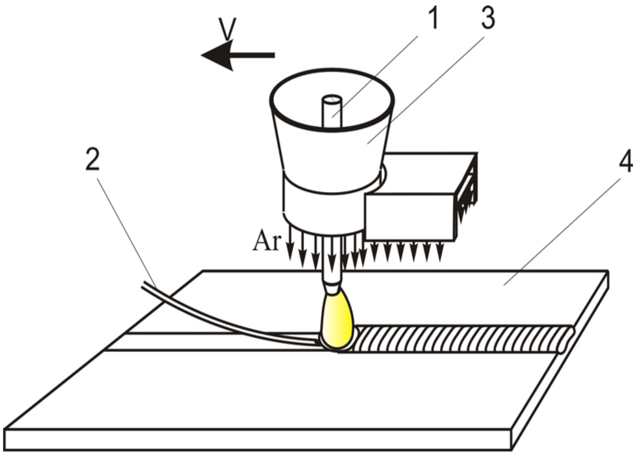

Fig.1. TIG welding process

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Results

FEM simulations are nowadays useful to predict the weld pool shape for various combinations of process parameters from the temperature distribution plots. In this work the simulation of the thermal field during the TIG welding process of VT23 titanium alloy joint is presented. The thermal analysis is concentrated on the prediction of the heat transfer in the weld. A distributed volume heat-source was validated on the basis of the comparison with the experimental specimen cross section. The temperature distribution in the overall weldment, the shape and size of the fusion zone, heat affected zone, the maximum cooling speeds in different parts of HAZ were predicted. To compare simulation results with the experimental values, welding of titanium alloy VT23 was carried out. VT23 plates of size 200x100x10 mm were prepared.

Welding was done with different modes to analyze and predict the geometry, the shape of the seam and the depth of weld penetration.

For the calculation of the thermal conditions accompanying the process of melting the metal surface, a mathematical model was used, which is based on the differential equation of heat conduction in a three-dimensional Cartesian coordinate system. The finite element thermal simulation of TIG welding was performed on 10 mm thick VT23 titanium alloy. The size of model used for the experiment was 200x100x10 mm (Fig. 2).

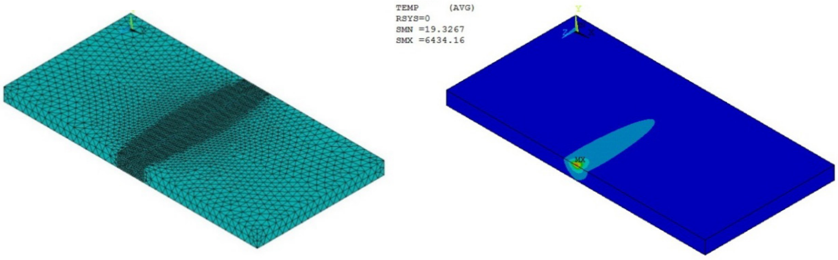


Fig. 2. Three dimensional finite element model meshes

The plate is symmetrical about the plane passing through the weld line. The geometrical model is divided into various regions. The fine mesh is made in the weld region to apply heat flux accurately. The region way from the weld line is meshed with a coarse mesh. A three-dimensional finite element mesh model as shown in Figure 3 is used for the FE analysis. 2D mesh is used for creation of heat source fitting for the thermal analysis [12].

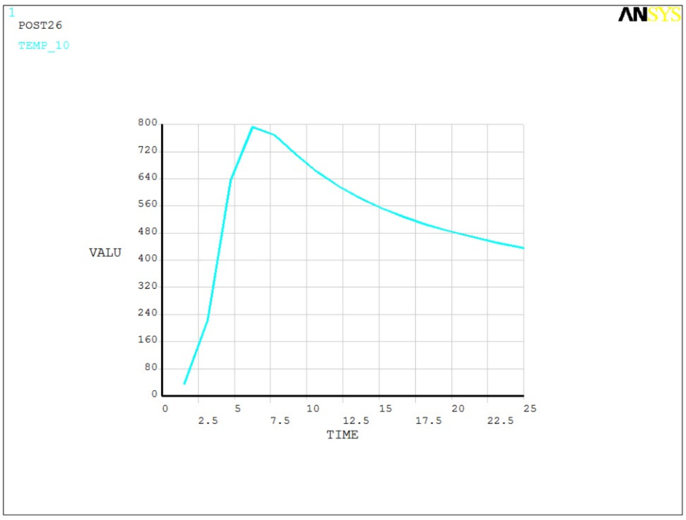


Fig. 3. Calculated welding thermal cycle

The material database is created based on the temperature related thermo-physical and mechanical properties of the material are taken from literature. The double ellipsoidal heat source parameters are obtained by the iterative manner. The obtained heat source is adjusted and saved in the function database for the use of weld wizard. After obtaining the heat source parameters for the simulation, final FE simulation is carried out using ANSYS and the results are obtained. Based on the results, isotherms of maximum temperatures were built, using which we determined geometry and dimensions of weld penetration zone, HAZ polymorphic transformation. Comparison of the results of the calculation forms of penetration zone with the experimental data showed satisfactory reproducibility.

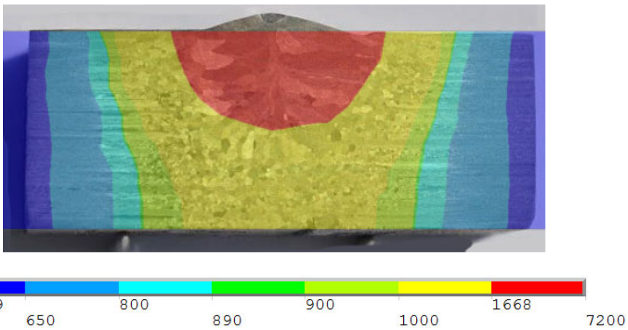
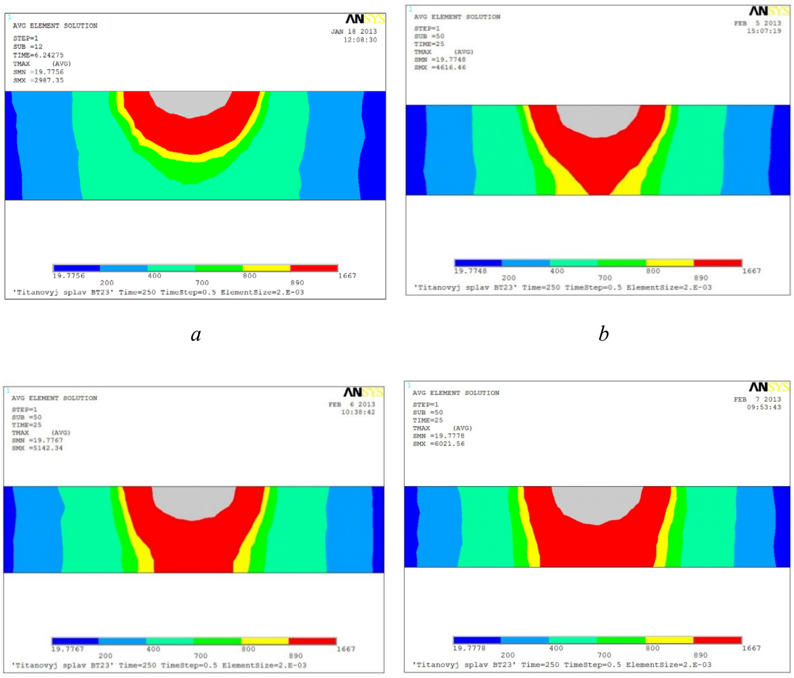


Fig. 4. Verification of developed FE model

As shown in Figure 4, developed mathematical model allowed to study effect of different welding modes and changing of welding heat input on the size and geometry of the penetration zone and heat affected zone. The simulation allowed to evaluate similarity to existing experimental results in studies related to welding processes [13], showing the temperature distribution of the work piece, and the cooling curves at the point of highest temperature and on the fusion line.

Obtained results of TIG welding using various modes are shown in Figure 5.



a *b*

c *d*

Fig. 5. Calculated data of mathematical modeling of TIG-welding:
a **– I=220A, U=11V, η=0.43;** ***b*** **– I=306A, U=11V, η=0.43;**
c **– I=350A, U=12V, η=0.43;** ***d*** **– I=420A, U=12V, η=0.43**

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Conclusions

Finite element model was created for tungsten inert gas welding process based on differential equation of heat conduction in a three-dimensional Cartesian coordinate system. The results from the FE thermal analysis have been validated by comparing them to experimentally obtained cross-section of titanium alloy welded joint VT23. Based on quite satisfactory results, this work shows, that FE simulations can enable faster, less costly, and more optimized product development, as well as examinations of product performance that would not be possible even using very detailed prototypes.

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