International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** XII **Month of publication:** December 2021

DOI: https://doi.org/10.22214/ijraset.2021.39313

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue XII Dec 2021- Available at www.ijraset.com

Determination of the Influence of Laser Welding Parameters on the Weld Quality Assurance of Heat-Resistant Alloys

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Abstract: In this study, the method of determining the influence of laser welding parameters on the quality provisions of welded joints made with multicomponent heat-resistant alloys was developed. The regularities of the formation of the welded joint structure of multicomponent heat-resistant alloys obtained by laser welding have been studied. The causes and methodological approaches to eliminate defects in the form of hot cracks were identified.
Keywords: laser welding, multicomponent alloys, heat-resistant alloys, welded joints, quality

I. INTRODUCTION

Experience in the manufacture and operation of multicomponent heat-resistant alloys for aerospace products has necessitated the strengthening of quality requirements for such welded joints [1-5]. The quality of heat-resistant alloy welds is usually assessed using the requirements of EN ISO 13919-1:2019 "Electron and laser-beam welded joints — Requirements and recommendations on quality levels for imperfections — Part 1: Steel, nickel, titanium and their alloys". The specific list of tests and studies, required to meet the necessary level of quality is regulated by EN ISO 15614-11:2002 «Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 11: Electron and laser beam welding». Thus, to achieve the "B" weld quality level, it is mandatory to provide a visual inspection of 100% of connections; as well as carry out radiographic (and / or) ultrasonic control of 100% of connections; detect surface cracks in 100% of joints; convey a metallographic study of at least one microsection. Additionally (if necessary) the following tests can be carried out: hardness test; transverse bend test; longitudinal bend test; transverse tension test; toughness test.

The aim of this study was to determinate the influence of laser welding parameters on the weld quality assurance of heat-resistant alloys.

II. DEVELOPMENT OF THE METHODIC

According to the assigned task a method of determination of the influence of laser welding parameters on the weld quality assurance of heat-resistant alloys was developed. This methodology is based on the provisions of such standards as EN ISO 13919-1:2019, as well as EN ISO 15614-11:2002, while also taking into account the specific conditions of the usage of multicomponent heat-resistant alloys in aerospace industry products. Specifically, the methodology is aimed at selecting the quality level for any structure containing welded joints, created under such conditions. Unlike the methodics, specified by EN ISO, which only specify the characteristics of welded joints themselves, the developed methodology also takes into account different design features of the products: further processing (e.g. heat treatment); product load mode (e.g. static, dynamic); service requirements and conditions (e.g. temperature, pressure or vacuum level, environment), etc. Based on these considerations, the methodology included additional requirements for the quality of welded joints of heat-resistant alloys beyond those specified in the EN ISO standards and proposed the usage of additional testing methods at different stages of construction.

On the development stage these include: 1. X-ray phase analysis of the weld region; 2. Structural study with the usage of optical as well as electron microscopy; 3. Analysis of the chemical composition of the weld using X-ray spectroscopy; 4. Differential thermal analysis of the weld joints; 5. Determining the elastic modulus using ultrasonic methods; 6. Dilatometric studies, meant to allow to control phase transformations and determine the coefficient of thermal expansion of metal in the weld joints; 7. Determination of mechanical characteristics of weld joints in a wide range of temperatures and strain rates, at temperatures different from 20 °C; 8. Determination of heat resistance of weld joints by increasing the mass during exposure to air in the temperature range of 600-1200 °C.

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At the stage of mass production of the structure (destructive testing of a sample): 1. Structural study with the usage of optical as well as electron microscopy; 2. Analysis of the chemical composition of the weld using X-ray spectroscopy; 3. Determination of mechanical characteristics of weld joints in a wide range of temperatures and strain rates, at temperatures different from 20 °C; 4. Determination of heat resistance of weld joints by increasing the mass during exposure to air in the temperature range of 600-1200 °C. To test the feasibility of the developed methodic, samples of lap welded joints of heat-resistant alloy 86,7Nb-10,6Hf-0,48W-0,27Ta-0,94Ti-0,84Zr-0,30Si were produced using laser welding technology for metallographic research, as well as physical and mechanical tests.

III. RESEARCH METHODS AND EQUIPMENT

Laser welding of 2.0 mm thick lap welded joints made of multicomponent heat-resistant alloy with the following chemical composition: 86.7Nb-10.6Hf-0.48W-0.27Ta-0.94Ti-0.84Zr-0.30Si, was performed using "YLR-400-AC" fiber laser. The power of the laser radiation was constant and was 400 watts. The welding speed varied from 50 mm/min to 900 mm/min. The defocus value varied between +5 mm and 0 mm.

The specifics of the formation of weld joints that depend on the conditions of gas protection were studied by changing the flow speed of shielding gas, as well as its type. Argon and helium were used as shielding gases. The consumption of shielding gases varied within 5…20 l/min. According to the results of the performed tests it is established that the increase of shielding gas consumption from 5 l/min to 20 l/min affects the geometry of the weld joint and the surface condition after welding to a way smaller degree than the changing of the shielding gas type from argon to helium. In this case, an increase in the depth of penetration, the lack of color variability as well as the reduction of the width of the thermal zone was observed.

IV. RESULTS AND DISCUSSION

Metallographic studies of lap welded joints from sheets made of heat-resistant alloy 86,7Nb-10,6Hf-0,48W-0,27Ta-0,94Ti-0,84Zr-0,30Si with a thickness of 2 mm showed that the sheet structure consists of recrystallized coaxial grains about 60 µm in size (Fig. 1). On the boundary between the main material of the sheet and the weld joint a visible area with enlarged grain size (100-150 µm) was observed. This indicates the course of recrystallization in the heat-affected zone (HAZ). The cast structure of the weld consists of large columnar grains, in which the substructure is observed (Fig. 1). The length of the columns in the structure is oriented in the direction of heat dissipation during crystallization. The emergence of the aforementioned substructure indicates that the material undergoes significant deformation due to thermal strain. High temperature causes polygonization, which occurs as a result of deformation of the dislocation structures. The size of the polygons is around 8 microns.

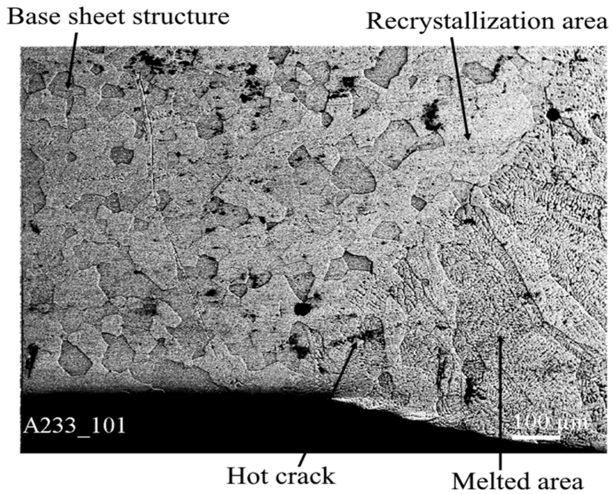

Fig. 1 Microstructure of the material in the area of the junction between the base sheet and the melted zone. A hot crack is visible at the end of the molten zone

Hot cracks are observed in the weld area (Fig. 2). The crack opens inside a large grain along the edges of the substructure. The opening of cracks at the boundaries of polygons or grains indicates that the process occurs at high temperatures, where the weakening of the boundaries due to the rapid formation of segregation by diffusion and the emergence of thermal strains through the temperature gradient is possible, which destroys the weakened boundaries of the structure.

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In addition to the formation of a polygonal structure, there is a release of particles in the molten zone (Fig. 2), which, as shown in Fig. 3, are enriched with hafnium. This means that with the rapid crystallization of the alloy niobium, which has a melting point 500 °C higher than that of the hafnium, initially crystallizes in an almost pure form. The release of α-Hf is therefore possible from the remaining liquid enriched in hafnium, at temperatures below 980 °C (Fig. 3).

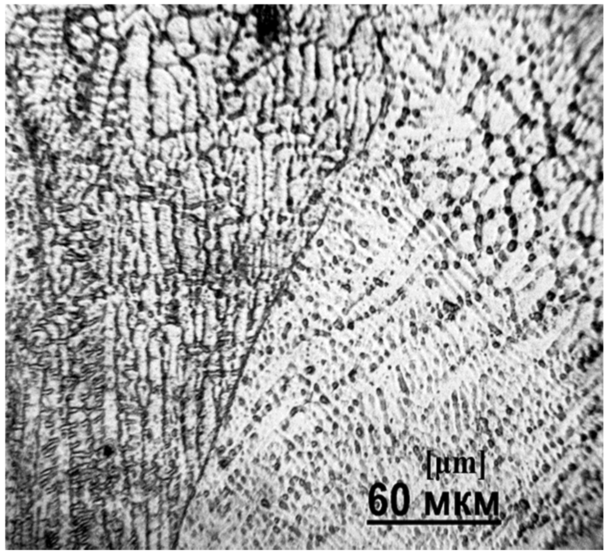

Fig. 2 Microstructure in the weld joint area

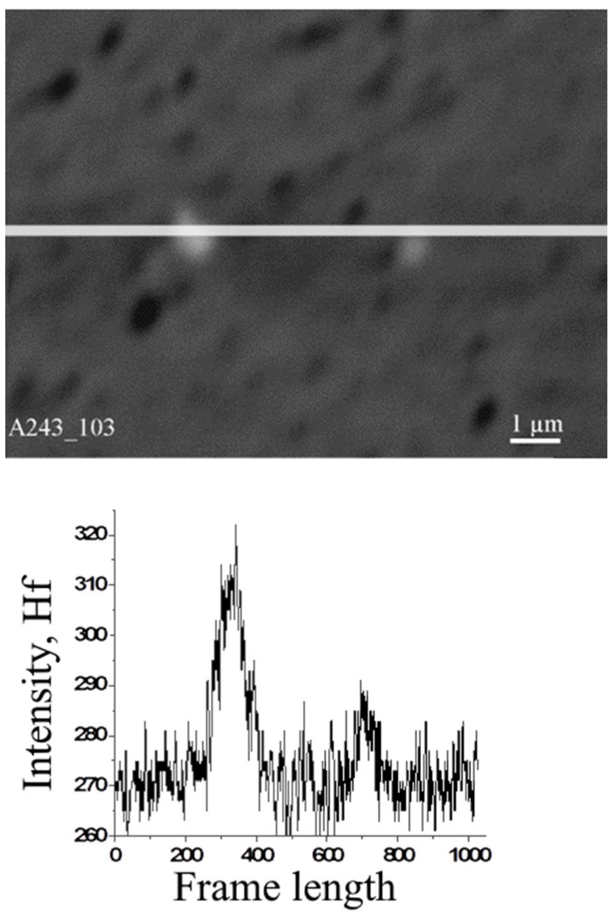

Fig. 3 Hafnium concentration along the line on the microstructure photograph

Hot cracks have also been found in the structure of the base material sheets. Here they also unfold at the grain boundaries (Fig. 4).

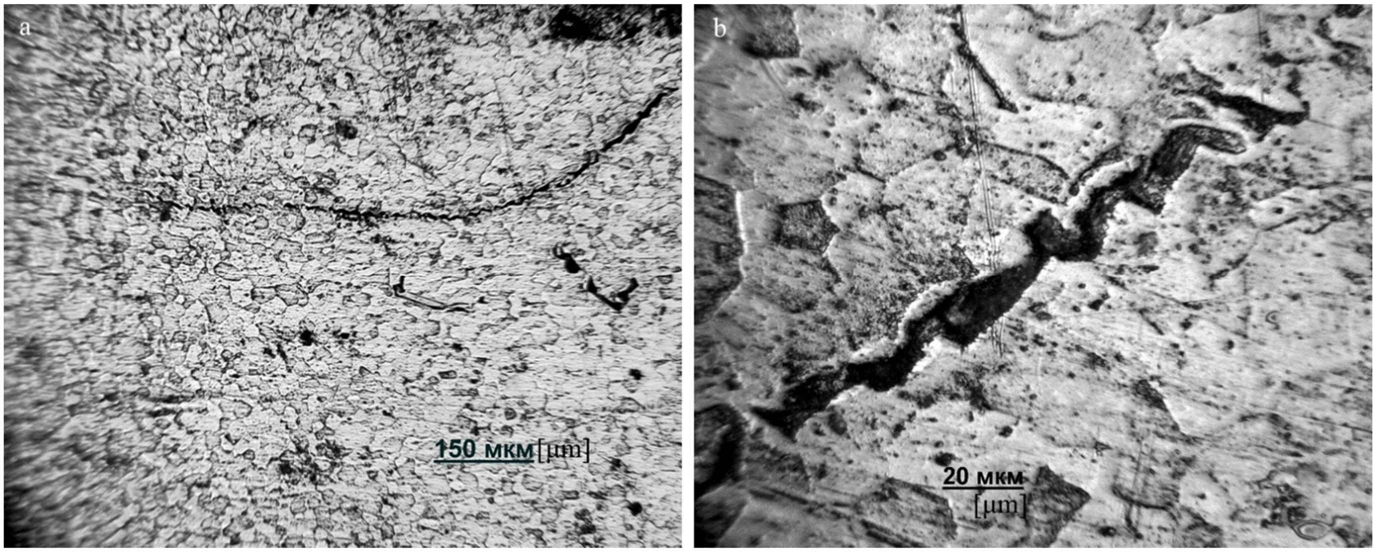

Fig. 4 Hot cracks in the base material

V. CONCLUSIONS

Alloy 86,7Nb-10,6Hf-0,48W-0,27Ta-0,94Ti-0,84Zr-0,30Si may have temperature ranges in which hardening of the material occurs with a loss of plasticity.

The weakening of the strength of the grain borders as a result of segregation was revealed. This leads to the fact that the resulting thermal strains do not relax thanks to the plastic deformation, but as a result of the opening of hot cracks at the grain boundaries.

Temperature-velocity modes of deformation during metal rolling and laser welding can lead to the realization of deformation due to slipping along the grain boundaries under the influence of thermal strains. This, in turn, leads to creation of gaps in a significant part of the grain boundaries.

Search for methods to eliminate temperature intervals in which the hardening of the material occurs with compounding loss of plasticity of both the base material and the welded joint is a promising area for further research on the subject. This entails research and development of methods of optimization of the chemical composition of the source material, as well as further optimization laser welding modes used in the process.

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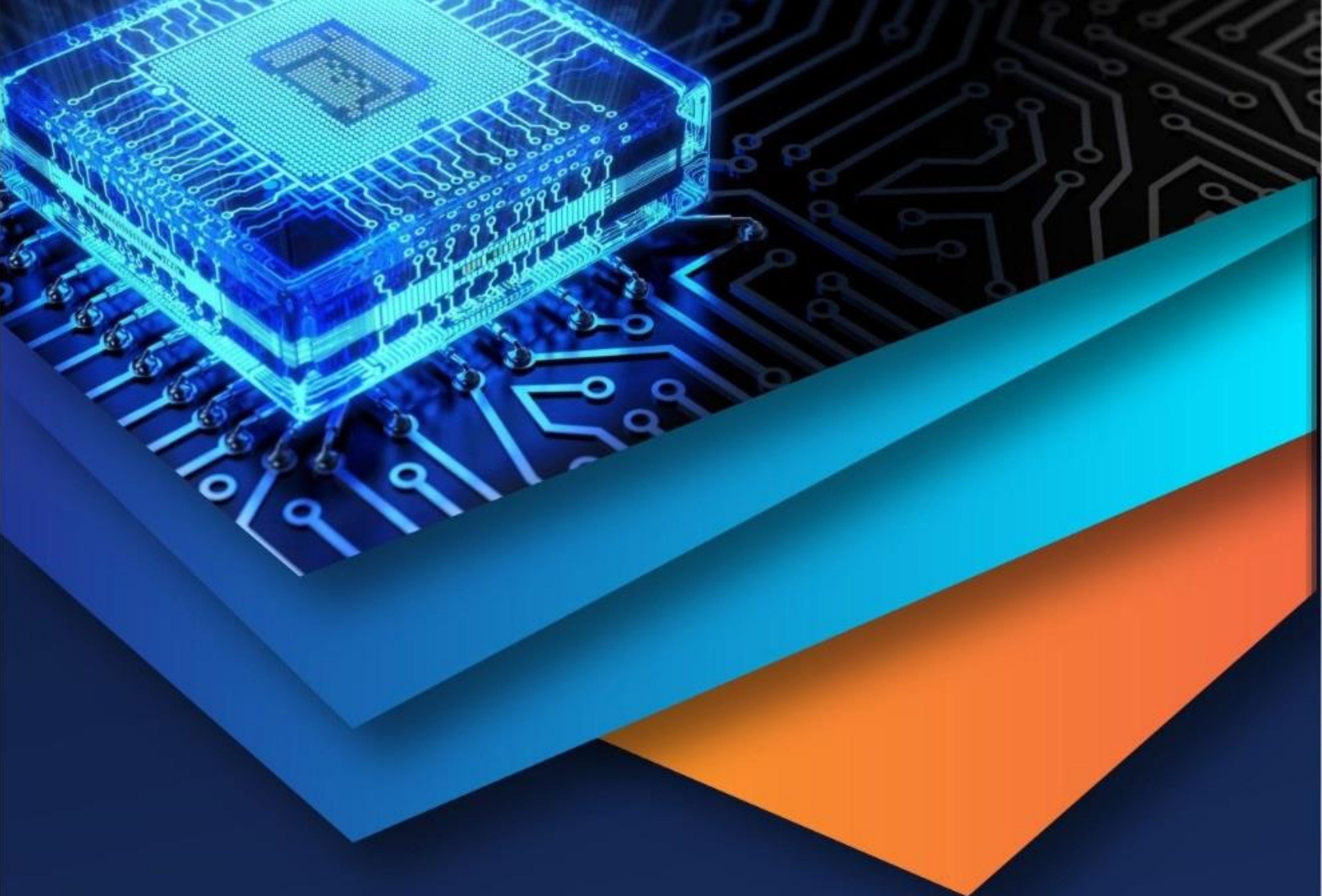

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