POSUDEK OPONENTA DISERTAČNÍ PRÁCE

Assessment of the Dissertation

Titul, jméno a příjmení studenta: Title, name, surname of student	Ying LI
Doktorský studijní program: Doctoral study programme	P0715D270027 Manufacturing and Materials
Téma disertační práce: Topic of the disseration	High temperature mechanical behavior of functionally graded material SS316L/IN718 fabricated by directed energy deposition
Školitel: Supervisor	prof. Ing. Ján Džugan, Ph.D.
Oponent: Opponent	doc. Ing. Jiří Kubásek, Ph.D.

Zhodnocení významu disertační práce pro obor
Evaluation of the importance of the dissertation for the field

The presented thesis deals with the impact of process parameters of LDED (laser direct energy deposition) technology and further thermal treatment on the microstructure and mechanical properties of SS316L and IN718 at ambient and increased temperatures. Both materials are studied separately and further Functionally Graded Materials (FGMs) combining SS316L and IN718 are prepared and analysed. In this case, especially materials with gradients of chemical composition from iron-based to nickel-based alloys, have garnered significant attention for applications that demand high strength, creep, and corrosion resistance indicating the relevance of the thesis for the development of new materials. Both the results obtained for individual materials and FGMs bring important knowledge about materials development by additive manufacturing techniques including the effect of thermal post-treatment and help to explain close relationships between microstructure and mechanical properties obtained from tensile and creep tests. The thesis is solved systematically and considers a rather wide range of variables affecting final material performance which further supports the high added value of the obtained data and results.

Vyjádření k postupu řešení problému, použitým metodám a splnění určeného cíle
Evaluation of the the problem-solving process, the methods used and the goal to be met

The LDED technology used in the presented work for materials preparation represents an advanced technology of additive manufacturing enabling the production of a wide range of custom materials of desired shapes faster and at a lower cost compared to the laser powder bed fusion (LPBF), making this technology more accessible to some industrial areas. Therefore, it is crucial to study the effect of this technology on the material's microstructure and mechanical performance. The author of the thesis Ying LI set several objectives to solve as a part of the study, which are in other words summarized as: 1) To investigate how LDED process parameters affect the microstructure and mechanical properties including their anisotropy of IN718 and SS316L. 2) To study the effect of heat treatment on the microstructure evolution and high-temperature mechanical properties of IN718 and SS316L. 3) To optimize the LDED process concerning the mechanical performance of IN718 and SS316L at high temperatures. 4) To successfully prepare and characterize the IN718/SS316L FGM material. All these objectives were fulfilled. The materials were characterized by standard techniques in the field of study including optical, scanning and transmission electron microscopy equipped with detectors like EDS and EBSD. Furthermore, X-ray diffraction, tensile tests and creep tests were applied. All the results have high quality and support the conclusions of the thesis. A minor deficiency can be considered in missing legends in some presented figures especially showing EBSD results (eg. 7-3). Also, the quality of creep curves in Fig. 6-6 for IN718 seems worse than for 316SS but the reason is not explained.

Stanovisko k výsledkům disertační práce a k původnímu konkrétnímu přínosu předkladatele disertační práce
Statement to the results of the dissertation and on the original contribution of the submitter of the dissertation

The results and discussion presented in the thesis are supported by obtained data using standard measurement techniques. All results are of good quality and in a majority of cases the statistic is considered. However, according to Fig. 7-7 b, it seems that different amounts of samples have been measured for specific conditions. This needs some clarification. The contribution is observed in several areas. Firstly, the optimization of process parameters for individual materials like IN718 and SS316L concerning their mechanical performance is worth studying due to the huge potential of this technology for commercial applications. Secondly, the relationships between mechanical properties at the laboratory and mainly at increased temperatures are systematically described and explained enabling to further tailor the materials' microstructure according to the final requirements on mechanical properties. Last but not least, the connection of both materials and the creation of FGM by LDED is a rather new idea bringing significant potential in new materials development. Obtained results regarding microstructure evolution, especially at the interface of both materials in the diffusion zone and the effect of heat treatment on the microstructure changes bring new knowledge to the selected field of study. Finally, it can be concluded that the author of the thesis succeeded in the preparation of superior FGM material combining excellent strength, ductility and creep resistance.

Vyjádření k systematice, přehlednosti, formální úpravě a jazykové úrovni disertační práce

Statement to the systematics, clarity, formal adaptation and language level of the dissertation

The thesis is systematically organized and clearly organized into several chapters. The introduction part has 19 pages and introduces the reader to the problematics of functionally graded materials, Laser directed energy deposition (LDED) technology, state of the art about SS316L/IN718 gradient structures and creep behaviour of SS316L and IN718. The following experimental part including a discussion, experiment description, results and discussion has 60 pages and deals in separate chapters with SS316L, IN718 and FGMs and their properties. The thesis contain some minor mistakes in language (Laser-based directed energy deposited process (LDED) instead of laser-based directed energy deposition process (LDED); TiAlV instead of Ti6Al4V; graduation steps instead of gradation steps; testimng instead of testing; perserves instead of preserves; the creep rates correspondingly rose instead of rise). Sometime there is a future time selected in the thesis although experiments were done (eg. page 40). In Figure 6-5 b, there is missing the designation of the y-axis. Furthermore, reference is missing on page 38 ("is shown in Error! Reference source not found."), fig 4.2 has not appropriate caption and description (page 40) and not all abbreviations are explained (eg. ZigZag CFC; CF; Dxy). Also on page 59 - Figure 5-4c is missing in the figure caption. It is also suggested that in several cases, phases could be pointed directly in Figures. But generally, the observed shortcomings are of minor meaning and correspond to the magnitude of the work and do not disturb the understanding of the work.

Vyjádření k publikacím studenta

Statement to student's publications

The publication activity of the student is pretty good while Y. Li is the first author of 6 papers in highly ranked impacted journals – 5 from Q1, 1 from Q2 and further co-author of 5 papers in journals from Q1 and Q2. The topicality of these papers is related to the materials presented in this thesis (SS316L, IN718) and specific papers elaborate in detail on the relationships between properties and microstructure of materials in connection with their preparation techniques and conditions. The articles address current challenges in materials development, especially in connection to additive manufacturing. In summary, the student's contribution to basic and applied science is unquestionable and reached results document his professionalism and hard work.

Celkové zhodnocení a otázky k obhajobě

Total evaluation and questions for defence

In summary, the thesis is well prepared and solves an interesting and highly actual topic related to the processing of SS316L, IN718 and FGMs by LDED and the influence of processing conditions on materials performance. The obtained results are supported by measured data and presented clearly both in the text and in appropriate graphs and figures. Only minor inconsistencies and errors appear in the text. The tasks of the thesis fulfil the established objectives and the conclusions and findings of the thesis are clearly presented. Therefore, the thesis is unequivocally recommended to the defence and it is suggested to award Mr. Li the degree of PhD.
Based on the content of the thesis, I would like to ask several questions:

1) What is the meaning of the scanning strategy designated a ZigZag CFC + CF?
2) Several times it is mentioned in the text that the cooling rates of LPBF and LDED are significant. Furthermore, the author mentions on page 31 that the cooling rate of LDED is relatively low. Could you please clarify what cooling rates can we expect for studied materials in LPBF and especially in LDED, which have been used?

3) What was the reason for the selection of 650 °C for creep tests? Why you did not study materials also at different conditions?
4) EBSD analyses have been performed for several samples including 316L. Did you also analyse some Kernel maps to visualise local stress or calculate even some dislocation maps? If there are some results, could you show the differences between samples SDM800 and SDM1600?
5) In chapter 6, it is missing the description of selected parameters for creep measurement. In Figure caption 6-6 it is further mentioned that the parameters are 650°C/750MPa. Why did you select so high stress of 750 MPa which generally did not enable you to do the comparison with the as-built state? Furthermore, FGM materials were measured at 650°C/225MPa, so there is a bit of inconsistency regarding IN718.
6) How and why the specific temperatures for annealing of 316 stainless steel were selected? Furthermore, it is described that Mn- and Si-rich oxides grow but decrease in number with increased temperature of annealing. How does it work exactly?

Doporučuji disertační práci k obhajobě | ano (yes) | X | ~~ne~~ (no)

I recommend the dissertation for the defence

Datum 24.9.2024 **Podpis oponenta:**

Date Signature of opponent