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Report on the Habilitation Thesis Dr. Josef Stráský.

Dear prof. Zdeněk Doležal,

I am very pleased to write the report of the habilitation thesis of Dr. Josef Stráský. The habilitation thesis entitled Advanced Titanium Alloys for Medical Applications consists of a cumulation of a total of 12 published papers. The work focuses in two different but complementary lines of investigations for titanium alloys for medical applications: the development of new alloys, and the thermomechanical treatment to obtain ultra fine grained materials. The manuscripts that compose this thesis were published in highly ranked journals such as Materials and Engineering C and Journal of Alloys and Compounds, in open journals such as Metals and Materials, there are 2 book chapters and 3 conference papers.

General appraisal.

Dr. Stráský has been working in the last years on a topic relevant not only for the scientific community but also for the industry and the medicine in general. The objective is clearly exposed: to increment the strength of biocompatible titanium alloys achieving minium Young's modulus to avoid elastic incompatibilities with the bones. The work deals with development of new materials, advanced methods of materials characterization, and materials processing.

The structure of the habilitation thesis and the writing style allows a clear and fluid reading. The topic is firstly introduced from the very basics, and rapidely the state of the art moves to describe the metastable beta alloy for medical use. The following 2 chapters discusse the main outcomes of the two here presented topics. The published as well as the unpublished work are summarized. The conclusions and outlook are presented in chapter 5. Finally, the references as well as the reprints of the publications are listed.

Introduction.

Basic concepts on titanium and classification of titanium alloys are introduced in the beginning of this chapter. Some aspects of the use of titanium alloys are discussed. The chapter then discusses specifically phase transformations in metastable β-Ti alloys and the correlation of phases with the Young's modulus, whether these phases are formed diffusion controlled or by diffusionless transformations. Strengthening mechanisms are shortly reviewed for Ti alloys, although it can be applied generally for any alloy. The strain hardening and the grain refinement may be achieved during severe plastic deformation, and the contributions to the stresses are given by equation 1 and by the increment of the dislocation density, respectively. Well-known is the strengthening by solutes, and specifically for interstitial solutes such as oxygen. Especially in metastable beta alloys, large amount of oxygen possible without decreasing much the ductility. Specifically for titanium alloys, the precipitation of the alpha phase (precipitation or transformation?) strengthens the material considerably. Subsection 2.4. gives a short overview of titanium as an implant material. It describes the history of these type of materials as implants and compare some issues with classical alpha+beta alloy. A contextualization of these titanium alloys with respect to other type of materials/alloys would have been interesting. Nevertherless, steels are shortly named in the publications remarking their high Young's modulus and high strength. Ultra-fine grained Ti alloys are obtained by severe plastic deformation methods. The both most well known methods as well as their particularities are discussed shortly in the thesis. On the other hand, much less on the strengthening mechanism itself is written, although these aspects are well covered in the articles referred to the topic. With respect to the cited works in general, I missed the works of Appolaire, Guatier, Germain, Jackson, etc. in the European region dealing with metastable alloys and their phase transformation and some more new references.

Scientific outcome.

Development of Ti-Nb-Ta-Zr-O biomedical alloys

The goal of reaching high strength material by adding oxygen seems to be incompatible with the goal of decreasing the Young's modulus for implant applications. At least this is what one may think in the first approach. Dr. Stráský and his group have demonstrated, that titanium alloys can be strengthened with oxygen, a strong strengthener compared to substitional solid solution elements, and at the same time keep the Young's modulus low. The experience of the group in biomedical alloys based on the system Ti-Nb-Ta-Zr-O allowed them to hypothesized that the low elastic modulus occurs when the whole chemical composition chosen results in a metastable alloy close but above the martensitic transformation. In this way, the amount of beta stabilizers (Nb) can be decreased, and the Ta avoided, to get the combination of high strength and low Young's modulus. Happyly, some non-published results seems to confim it. Also additions of Fe and Si have shown to be unnecessary to achieve high strength. Still this relationship of the low elastic modulus and the "proximity" of the chemical compostion to the martensitic transformation is not explained from the physical point of view.

Of course, as Dr. Stráský also noticed, static mechanical properties are not enough for implants. Therefore, as-cast material was transformed into wrought material. The workability and the microstructure development of the material were studied by means of thermomechanical treatments at lab scale. Alloys were then tested for fatigue resistance in as-cast and wrought conditions. Die forging and hot rolling have shown to close the as-cast pores, to increase fatigue strength and to increase mechanical properties in general. Interesting in this case would have been the information about the elastic modulus, whether texture modified its vaule.

Ultra-fine grained Ti alloys for biomedical use.

SPD methods were used for a large amount of alloys in the literature. It is based in the contribution of strengthening by strain hardening and grain refinement. Unfortunately these methods can be used for relatively small products. The work of Dr. Stráský is based in the characterization of the microstructure evolution after applying these methods, including the identification and quantification of defects, and the correlation of these highly deformed microstructures with the phase transformation in the ageing. Advances techniques were smartly used to reveal that depending on the amount of strain, different type and amount of defects were obtain. These findings are relevant fo Materials Science in general. The strengthening effect seems (as expected) to be lost by increasing the temperature due to fast recovery and recrystallization. At this point it is valid to ask whether ageing has to be carried out after SPD in a traditional way, or new processing routes should be designed. This aspect was also explored by Dr. Stráský to reveal high mechanical properties after heat treatments due to fine dispersed alpha. I always miss in these type of experiments some hints about the temperature increment, if any, due to friction, plastic deformation, and low heat transfer.

Conclusion and outlook

The chapter summarizes in two paragraphs the main outcomes in a very general way. Sound conlcusions of the whole work would have been expected at this stage, although much can be found in the publications. The outlook is focused on different topics such as powder metallurgy, additive manufacturing and thermomechanical treatment. The topics are very wide, and a context would be expected.

Some final questions pop at this final stage: a) was the final objective of low elastic modulus and high strength achieved?, b) at which point of strength and Young's modulus is the objective achieved?, and finally c) what is the strategy and the topic of research after achieving this punctual objective?

Similarlity report.

A high percentage (12%) corresponded to the repository of the Charles University of Prague (I guess due to thesis and publications). Some similar text were found on general statements (even in the aknodlegment). The thesis is based on the cumulation of published papers which are correctly referenced. Non published work was included and similarlity check is less dense when discussing non published work and describing future work. I don't see any critical point referred to plagiarism.

Final comments and outlook.

In general, I consider the quality of the whole work to be very good. The contribution to the scientific community working on titanium alloys in general is highly appreciated. Particularly, the contribution of the author to the publications is substantial in executing and guiding the resarch.

I am positive that Dr. Stráský will find large amount of interested external scientific and industrial partners for cooperation in the future. This will expand his horizons to finally find his personal research path. Dr. Stráský is an outstanding scientist. I had also the opportunity of meeting him personally, and I always appreciated his passion for science in particular and his good humor and kindness in general. I sincerelly endorse his promotion without any reservations.

For any question, please don't hesitate to contact me.

Sincerely yours,

Cecilia Poletti

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