NELSON MANDELA
UNIVERSITY

Centre for HRTEM
South Campus
Port Elizabeth
Mobile: +27 832992086
Email: Jan.Neethling@mandela.ac.za

14 March 2025

To whom it may concern

Re: Evaluation of the PhD dissertation by Mr Fedor Evgenievich Popov

Please find below the foreign scientific advisor's evaluation of the dissertation by Mr Fedor Evgenievich Popov titled "Development and study of the technology for obtaining oxide-dispersion hardened steel for use in nuclear power engineering", submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (PhD) in specialty 8D07202 - "Metallurgy of ferrous and non-ferrous metals".

The PhD dissertation focuses on the development of advanced materials needed for the next generation of nuclear reactors (Generation–IV and thermonuclear) which will operate at much higher temperatures and pressures. This is a highly relevant research topic because sources of clean energy production are of critical importance globally. The stabilization of stainless steel without nickel overcomes the disadvantages of using austenitic steels as structural materials in nuclear reactors as long-lived radionuclides are generated by the presence of nickel in the austenitic steel. This improved stainless steel call oxide dispersion-strengthened (ODS) steel is created by dispersing yttrium oxide nanoparticles in the steel. The oxide nanoparticles increase the radiation resistance of the material and ensure its stability under extreme operating conditions. The material developed and its production technology has important applications in the nuclear power industry because it can increase the safety and efficiency of nuclear reactors.

The candidate discussed the challenges associated with the traditional production of ODS steel and motivated why it was important to find new methods for the production of ODS steels that can overcome these challenges. This dissertation includes a comprehensive analysis and testing of various technologies for the production of ODS steel ingots. The most promising method for smelting steel with an optimal percentage of yttrium oxide was selected. Detailed studies of the rheological properties of the material were carried out in order to create a database for accurate modeling (by the finite element method) of the processes of intense plastic deformation of ODS steel. Intense plastic deformation methods are used to improve the mechanical properties of the material as well as its radiation resistance at high temperatures.

The research objectives include a comprehensive literature and patent review of existing methods for producing ODS-steel ingots and ways to improve the structure and properties of the ingots. A second objective was the study of the effect of intense plastic deformation by radial shear rolling on the evolution of the cast structure of steel ingots containing reinforcing particles of yttrium oxide in order to form an ultrafine-grained material structure with improved properties.

A wide variety of experimental techniques were used to investigate the prepared samples. The microstructure and morphology of the ODS steel samples were analysed using optical microscopy (OM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Energy Dispersive X-ray spectroscopy (EDS)

in SEM and TEM was used determine the ODS steel composition and distribution of yttrium oxide in the steel matrix. Selected Area Electron Diffraction (SAED) and electron backscatter diffraction EBSD were used to determine the texture of the samples and the crystallographic orientation of grains. The measured rheological properties of the prepared material were used in computer simulations (by the finite element method) of rolling processes in order to optimize deformation parameters. This comprehensive approach has allowed for a detailed study of methods for producing ODS steels and their properties.

The scientific impact and novelty of the research may be summarized as follows:

- A new technology has been developed for the endogenous formation of dispersed yttrium oxide particles in steel based on the internal oxidation of metallic yttrium during smelting.
- The effectiveness of radial shear rolling of steel ingots with strengthening yttrium oxide particles was experimentally confirmed.
- The new technology allowed the production of oxide-dispersion-hardened steel by induction melting in a non-vacuum environment with the addition of 2% metallic yttrium.
- For the first time, 8 different exogenous and endogenous methods of introducing yttrium oxide into a 12X13 stainless steel melt have been experimentally studied.
- A database of rheological properties of ODS steels has been created to predict their characteristics. Based on the created database, various processes of plastic deformation of molten steel were modeled.

The candidate's personal contributions include the direct implementation of all stages of the research, including the development of hypotheses, setting experimental tasks, conducting experiments and analyzing the results obtained. The research by the candidate has already been documented in 6 journal publications and 2 conference presentations. Based on the comprehensive and detailed study carried out and the excellent results obtained, I strongly recommend that Mr Fedor Evgenievich Popov be awarded the PhD degree. I therefore recommend that Mr Popov be invited to the public defense of this dissertation work for the Doctor of Philosophy (PhD) degree in specialty 8D07202 - "Metallurgy of ferrous and non-ferrous metals".

Finally, I would to congratulate the candidate and his supervisor on producing a comprehensive and excellent PhD dissertation.

Yours faithfully,

Professor Johannes H. Neethling (PhD, MSc physics)
Foreign Scientific Advisor to Mr FE Popov
Centre for HRTEM
Department of Physics
Nelson Mandela University

NELSON MANDELA UNIVERSITY
Centre for HRTEM

Signed by: Prof EJ Olivier
Director of the CHRTEM
Nelson Mandela University
Port Elizabeth, South Africa