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SUMMARY OF THE HABILITATION THESIS

STUDIES AND RESEARCH ON THE EVALUATION AND IMPROVEMENT OF TECHNICAL PERFORMANCE OF EQUIPMENT USED IN THE OIL AND GAS INDUSTRY

Fundamental Field: Engineering Sciences
Doctoral Field: Mechanical Engineering

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SUMMARY OF THE HABILITATION THESIS

The habilitation thesis entitled "*Studies and Research on the Evaluation and Enhancement of the Technical Performance of Equipment in the Oil and Gas Industry*" presents a part of the scientific research activity disseminated through publications, as well as the teaching activity I have conducted since obtaining the scientific title of *Doctor* in the year 2000, with the distinction *Cum Laude*, in the fundamental field of Engineering Sciences, in the doctoral field of *Mechanical Engineering (Order of the Minister of Education and Research No. 5201/23.11.2000)*, following the defense of the doctoral thesis entitled "*Research on the Construction of Flexible Tubing Used in the Oil Industry*" (scientific advisor: Prof. univ. Dr. Eng. Vlad Ulmanu).

The habilitation thesis, authored by Associate. Dr. Eng. Ec. Zisopol Dragoș-Gabriel, extends over 183 pages, containing 212 bibliographic references (72 of which are authored by the researcher) and is structured into two parts: *SCIENTIFIC AND PROFESSIONAL ACHIEVEMENTS* and *CAREER DEVELOPMENT AND FUTURE PLANS*. The paper includes 21 mathematical formulas, 41 tables, and 111 figures.

The SCIENTIFIC AND PROFESSIONAL ACHIEVEMENTS are highlighted in the first part of the habilitation thesis through three chapters, namely: contributions to enhancing the durability of threaded joints in special couplings; contributions to the modernization of copper pipe assembly systems for their use in natural gas supply installations; and contributions to the evaluation and enhancement of the technical performance of additively manufactured products through thermoplastic extrusion.

The studies and research presented in the first chapter focus on optimizing the parameters of the heat treatment applied to 40CrMoV13-9 steel to improve its mechanical properties for manufacturing special couplings, thereby increasing the durability of their threaded joints. Additionally, the optimization of the cold plastic deformation rolling parameters for threaded joints in special couplings made from 35NiCr6, 34CrNiMo6, and 42CrMo4 steels is explored. The optimization of the heat treatment applied to 40CrMoV13-9 steel was achieved through the processing and interpretation of resistance, toughness, and fatigue test results obtained for different heat treatment variants (quenching in two media—oil/synthetic medium R3 and tempering at various temperature-time holding combinations). It was determined that the appropriate heat treatment for special couplings made from 40CrMoV13-9 steel consists of heating to 870°C, followed by quenching in the synthetic medium R3, and subsequent tempering for two hours at 620-630°C. The recommended heat treatment regime, derived from experiments conducted on samples from a single steel batch, must be adjusted in practice considering the chemical composition of the batch used in coupling manufacturing. The optimization of cold plastic deformation rolling parameters for threaded joints in special couplings made from 35NiCr6, 34CrNiMo6, and 42CrMo4 steels aimed to increase their durability.

The optimal rolling regime through cold plastic deformation of threaded joints corresponding to special fittings made from the steel 35NiCr6, 34CrNiMo6 and 42 CrMo4 was established by analyzing the effects of strain hardening (on smooth specimens, specimens with stress concentrators, and real components) on: the quality of rolled surfaces, residual deformations and stresses, modifications in mechanical properties obtained from tensile and fatigue tests, microstructures, and surface micro hardness of rolled layers.

By analyzing, processing, and interpreting the results obtained from the studies and research conducted, the optimal cold rolling technology was determined by establishing: the geometry of the deforming roller, the mechanical device for rolling the threads of special couplings, the machining allowance for the rolled component, and the parameters of the rolling regime: pressing force on the deforming roller, the number of passes of the roller over the threaded component, the relative speed between the deforming roller and the rolled component, the rotation speed of the rolled component, and the lubrication conditions with transmission oil. The criterion for transferring the optimized strain hardening regime from smooth specimens and specimens with stress concentrators to the threads of special couplings made from 35NiCr6, 34CrNiMo6, and 42CrMo4 steels was achieving the same surface hardness after rolling. Research conducted on specimens with stress concentrators determined the optimal rolling pressure for cold plastic deformation, which is significantly high. Considering this observation and the fact that rolling specimens with stress concentrators at lower forces resulted in significant fatigue strength improvements, it is proposed that the optimal cold rolling pressure for NC 50 threads in special couplings be 55×10^3 N/mm². The data obtained from these studies and research were validated within S.C. UPET Târgoviște.

The second chapter of the paper summarizes the results of studies and research conducted on modernizing copper pipe assembly systems for their use in natural gas supply installations.

Globally, there is a trend towards widespread use of copper as a material for natural gas supply systems (liquefied natural gas, methane gas, propane-butane, etc.), fire suppression systems, solar energy systems, industrial and medical gases, compressed air pipelines, radiator heating (underfloor or surface heating), air conditioning systems, and other devices involving heat transfer.

The requirements for strength and technical safety in natural gas installations have led to the authorization of two copper pipe fitting assembly technologies: hard soldering (brazing) and pressing (crimping). Crimping, regulated by German standards DV GW 534 and DV GW VP 614, is preferred over brazing due to several advantages, such as: a crimping duration of approximately 4 seconds (30% shorter than brazing), installation warranties of up to 50 years, elimination of soldering/welding materials and, consequently, preparatory and post-assembly cleaning operations, reduction of corrosion risks in copper pipes due to flux residues/thermal effects, removal of fire prevention measures for work in hazardous locations (wooden structures, silos, etc.), elimination of mechanical stresses in the piping system since crimping can be performed after installation in its final position, and more.

In conclusion, the modernization of copper pipe assembly systems for their use in natural gas supply installations requires the implementation of press-fitting technology.

The technical safety requirements for natural gas utilization installations are stringent, and the technical standards for the design, execution technology, and operation of installations made from copper pipes and fittings are based on a set of technical certification procedures for the assembly technology and experimental verification of the assemblies' behavior under all types of mechanical, thermal, fatigue, and tightness stresses specific to natural gas use.

In this context, the paper presents the results obtained in the development of the assembly technology by pressing copper pipe fittings used in natural gas supply installations. After the creation of experimental models, a set of testing procedures was developed to certify the quality of non-detachable assemblies. Subsequently, specific equipment was designed and manufactured for testing the copper press-fitted assemblies. The experimental verification procedures for the quality of copper pipe-to-fitting press-fitted assemblies were designed to evaluate the fulfillment of all technical conditions that ensure the safe operation of modern natural gas supply installations, both under normal operating conditions and in accidental situations caused by earthquakes, fires, etc. The paper places special emphasis on verifying the high-temperature operational capability of copper pipe-to-fitting press-fitted assemblies used in natural gas supply installations.

The experimental results presented in the second chapter of the habilitation thesis form the basis of the certification process for the design, execution, and operation of natural gas utilization installations made by press-fitting copper pipes and fittings. Considering that the certification process for the design, execution, and operation of natural gas utilization installations made by press-fitting copper pipes and fittings has not yet been finalized in Romania, we are in advanced discussions with a company interested in developing a research contract aimed at obtaining technical certification, following the model established in other European Union member states (Germany, Italy, France, Austria, the Netherlands, Bulgaria, Hungary, the Czech Republic, Slovakia) as well as in the United Kingdom, the United States, etc.

The studies and research presented in the third chapter of the paper focus on evaluating and enhancing the technical performance of additively manufactured products through thermoplastic extrusion. The synergy between the additive manufacturing process and its economic advantages has positioned additive technologies at the forefront of future industrial production solutions and product customization. In the sustainable development of additive technologies, the materials used and the optimization of 3D printing parameters play a major role in improving the technical performance of additively manufactured products. In this context, the technical performance of 3D-printed products was evaluated through the thermoplastic extrusion of filaments made from polylactic acid (PLA), polyethylene terephthalate glycol (PETG), acrylonitrile styrene acrylate (ASA), recycled polyethylene terephthalate glycol (recycled PETG), and recycled acrylonitrile styrene acrylate (recycled ASA). To evaluate and ensure material quality, these materials were subjected to a series of tests to verify their physical and mechanical properties, ensuring they meet the technical specifications required for use in the environments and working conditions they were designed for, thereby contributing to the safety and reliability of the final products.

The improvement of the technical performance of 3D-printed products was studied through the optimization of additive manufacturing technology parameters using thermoplastic extrusion: layer height per pass (L_h), infill percentage (I_d), 3D printing speed (V_p), infill pattern (M_u), number of perimeters (N_c), part orientation (Op), extruder temperature (Te), 3D printer bed temperature (T_p), filament color, etc.

After a brief presentation of additive manufacturing technologies and the main types of materials established worldwide, the studies and research focused on evaluating and increasing the stiffness of gear assemblies made of straight-toothed cylindrical gears, additively manufactured through PLA thermoplastic extrusion. By analyzing, processing, and interpreting the results, an average meshing stiffness value of 17.91 Nm was obtained for cylindrical gears with a module of m = 1 and z = 60 straight teeth, 3D-printed from PLA via thermoplastic extrusion. The meshing stiffness of PLA straight-toothed cylindrical gears, 3D-printed through thermoplastic extrusion, is influenced by the infill percentage (Id) 5.44% more than by the layer height per pass (L_h). For these PLA gears, the minimum meshing stiffness value of 13.23 Nm was obtained for the gear set with R1 (L_h = 0.15 mm, I_d = 50%) and R2 (L_h = 0.15 mm, I_d = 75%), while the maximum stiffness value of 24.02 Nm was achieved for the gear set with R1 (L_h = 0.10 mm, Id = 100%) and R2 (L_h = 0.10 mm, I_d = 100%). To increase the meshing stiffness of straight-toothed cylindrical gears, the optimal parameters for PLA thermoplastic extrusion-based additive manufacturing are a layer height of L_h = 0.20 mm and an infill percentage of I_d = 100%.

The studies continued with the evaluation and improvement of the dimensional accuracy of gear assemblies made of straight-toothed cylindrical gears, additively manufactured from PLA via thermoplastic extrusion. Analysis of the results from measuring the shaft diameter (d) and bore diameter (D) of the gears with a module of m = 1 and z = 60 teeth demonstrated the significant influence of the layer height per pass (L_h) and the infill percentage (I_d) on their dimensions. For the shaft diameter (d), all dimensional deviations found after measuring the straight-toothed cylindrical gears fell within the ±0.10 mm tolerance, with the best results obtained for 3D printing with a layer height of L_h = 0.15 mm. The smallest dimensional deviations were observed in the gear set manufactured with a layer height of L_h = 0.15 mm and an infill percentage of I_d = 75%. For the bore diameter (D), 66.67% of the dimensional deviations observed after measuring the straight-toothed cylindrical gears fell within the ±0.10 mm tolerance, very close to the upper and lower limits. The smallest dimensional deviations were observed in the gear set produced with a layer height of L_h = 0.10 mm and an in ±0.10 mm tolerance, very close to the upper and lower limits. The smallest dimensional deviations were observed in the gear set produced with a layer height of L_h = 0.10 mm and an infill percentage of I_d = 50%.

The results of the studies and research on evaluating and increasing the compressive strength of lattice structures additively manufactured from PLA through thermoplastic extrusion represent another contribution to the third chapter of the paper. From this perspective, analyzing the results led to the conclusion that the average maximum compression force values for each of the seven infill patterns used in the additive manufacturing of PLA lattice structures (Grid, Tri-hexagon, Octet, Triangles, Cubic Subdivision, Gyroid and Cross 3D) fall within the range of 19.24

kN to 87.34 kN. The highest average maximum compression force, 87.32 kN, was obtained for the Triangles infill pattern.

The manufacturing precision of PLA lattice structures produced through thermoplastic extrusion is very high, ranging between 98.98% and 99.78%, with the highest precision recorded for the Octet infill pattern. The compression deformations of the additively manufactured PLA lattice structures fall within the range of 54.04% to 57.70%, with the maximum compression deformation of 57.70% observed for the Triangles infill pattern. The variation in 3D printing precision, within the range of 0.11% to 1.02%, resulted in a 3.66% variation in the compression deformation of the PLA lattice structures. From a techno-economic perspective, the optimal configuration for manufacturing PLA lattice structures via thermoplastic extrusion corresponds to the Cubic subdivision infill pattern, which achieved the highest ratio of utility value (lattice structure density) to production cost, V_i/C_p = 293.20 kg/(m^3 × euro).

The studies and research on evaluating and enhancing the performance of additively manufactured products using PETG, recycled PETG, ASA, and recycled ASA complete the third chapter of the paper. By analyzing, processing, and interpreting the experimental results, it was concluded that regardless of the material used (PETG/recycled PETG/ASA/recycled ASA), the infill percentage (I_d) is the most decisive factor influencing the tensile and compression behavior of the specimens manufactured through thermoplastic extrusion. The layer height per pass (L_h) has a much lower impact on the tensile and compression behavior of the additively manufactured specimens. For the PETG tensile specimens, the maximum average tensile strength reached 28.25 MPa. The average tensile strength of the recycled PETG specimens was higher by 29.17% to 31.59% compared to that of the PETG specimens. For the PETG compression specimens, the maximum average compressive strength reached 30.57 MPa.

The average compressive strength of the recycled PETG specimens was higher by 11.39% to 25.91% compared to the PETG specimens. For the ASA tensile specimens, the maximum average tensile strength was 43.24 MPa. The average tensile strength of the ASA specimens was higher by 3.64% to 8.13% compared to the recycled ASA specimens.

For the ASA compression specimens, the maximum average compressive strength reached 38.04 MPa. The average compressive strength of the ASA specimens was up to 7.02% higher compared to the recycled ASA specimens. The improvement in the operational performance of additively manufactured products using PETG, recycled PETG, ASA, and recycled ASA, in terms of tensile and compressive strength, was achieved with 3D printing using a layer height per pass of L_h = 0.10 mm and an infill percentage of I_d = 100%.

The data resulting from the studies and research were validated through articles published in journals indexed in WoS/Scopus.

The information regarding "*CAREER EVOLUTION AND DEVELOPMENT PLANS*" is outlined in the second part of the habilitation thesis through three chapters namely: education and professional training, teaching and research activity, and the development of the teaching and research career.

From the perspective of education and professional training, undergraduate, postgraduate, doctoral and postdoctoral studies lay the foundation for a career as a university professor and researcher.

In 1992, I graduated from the Faculty of Mechanical Engineering at the Oil and Gas Institute of Ploiesti, specializing in Technological Equipment (graduated with highest honors). Following the completion of my university studies, in 1992, I was appointed to the position of University assistant lecturer following a competitive selection process, at the Department of Petroleum Equipment Technology (currently the Department of Mechanical Engineering) within the Petroleum-Gas University of Ploiesti (UPG). Throughout my academic career, I advanced through the specific stages of university teaching positions up to the rank of Associate Professor. In 2000, I also graduated from the Faculty of Mechanical and Electrical Engineering at the Petroleum-Gas University of Ploiesti, specializing in Economic Engineering in the Mechanical Field - class of 2000 (top graduate).

After earning my PhD in 2000, I continued my professional development by attending various training courses, internships, and specialization programs, both domestically and internationally. These efforts were supported either by my employer or by professional training service providers and included individualized training, which has become increasingly significant with the rise of online education and AI-based learning tools. In recent years, I have attended numerous online courses on topics such as additive technologies, intelligent production systems, virtual reality elements, and artificial intelligence.

My teaching and research activity reflect my academic career progression.

My teaching has focused on various disciplines within Mechanical Engineering, such as: Technology of Materials, Materials and Primary Technologies, Value Engineering, Industrial and Construction Technologies, Fundamentals of Material Technology, Science and Technology of Materials Technology of Petroleum Equipment Construction, Ecotechnology, Materials Study, Additive Manufacturing Technologies, Industrial Robots and Flexible Manufacturing Lines, Advanced Production Systems, Risk and Safety Management for Hydrocarbon Transport and Storage Systems, Operational Production Management, Reliability of Petroleum and Petrochemical Technological Systems, Evaluation of Petroleum and Petrochemical Equipment Enterprises, Technology Design for Flexible Manufacturing Systems and more.

To provide students, master's students, and doctoral candidates with the necessary educational materials for these disciplines, I have authored or co-authored 13 books, laboratory guides, course support manuals, and specialized monographs since obtaining my PhD. Of these, 12 are in print format (three as sole author and five as first author), and one is available in electronic format on the Petroleum-Gas University of Ploiesti's platform. A very important approach in my teaching activity, which is closely connected to research work is the one related to the training students and master's candidates, preparing them for participation in scientific communication sessions, where some of the best among them have coauthored articles published in national and international journals, including those indexed in Web of Science (WoS). Additionally, my contributions include writing scientific reviews for university-level courses, manuals, monographs, and laboratory guides.

After obtaining my *PhD*, I continued *my research work* by participating in projects funded through various national and international competitive programs: ANSTI (2000–2002), RELANSIN (2000–2006), MCT (2001), MENER (2003–2005), CNCSIS (2004–2006), CNFIS (2002–2003), PHARE (2004–2005), POSCCE (2014), and EEA and Norwegian Financial Mechanisms (2019–2023). I also collaborated on projects with research and design institutes, commercial companies, and economic agents, particularly in the field of systems and equipment used in the oil and gas industry — including partners like Arcelor Mittal Tubular Products Roman S.A., Liberty Ostrava Plant 15 - Tubular (Czech Republic), S.C. Fevel Team SRL, SNTGN Transgaz SA Mediaș, and S.C. Electrica Muntenia Nord S.A. The scientific research I conducted has led to the development of innovative products, technologies, platforms, methods, studies, and services. This is reflected in my 26 articles published in Web of Science (WoS) indexed journals (all after obtaining my PhD), 4 patents (one indexed in Web of Science - Derwent Innovation and 3 patent applications submitted to OSIM in 2024), 11 articles published in Scopus-indexed journals (all after my PhD), 68 articles presented and/or published in conference proceedings and journals (47 after my PhD), and 83 research grants/contracts (70 after my PhD). My work has also been recognized through citation metrics, with a Hirsch index of 8 on Thomson Reuters, 9 on Scopus, and 14 on Google Scholar.

In 2023, at the inaugural "*Research Gala*" organized by the Petroleum-Gas University of Ploiesti, I was awarded the distinction of "*Best Experienced Researcher*" at the Petroleum-Gas University, and in 2024, I was ranked second in the same category.

Throughout my research, I involved students, master's candidates, and PhD candidates from both the Petroleum-Gas University of Ploiesti and other universities, such as the "Ferdinand I" Military Technical Academy in Bucharest and the Polytechnic University of Bucharest.

The research projects I've been part of have also provided favorable financial conditions for modernizing the laboratories within the Department of Mechanical Engineering at our university and for establishing new laboratories. Alongside my research teams and through individual efforts, I actively participated in equipping these laboratories and developing experimental setups and devices, contributing directly to the designing stands/devices and establishing new laboratories.

My teaching and research activities have played a crucial role in raising the national and international visibility of the Petroleum-Gas University of Ploiesti. An additional testament to this visibility is my affiliation with 10 professional associations. Since 2022, I have been a member of the scientific editorial committee of the *Engineering, Technology & Applied Science Research* journal, which includes 48 experts from 48 institutions across 31 countries. In 2023, I was elected one of the vice-presidents of the Romanian Association for Fracture Mechanics (ARMR), and since 2024, I have been a full member of the Romanian Academy of Technical Sciences (ASTR), Section X – Petroleum, Mining, and Geonomy Engineering. The experience gained in the fields of research and university management has helped me propose, organize, and finalize the signing sessions of several bilateral collaborations between the Petroleum-Gas University of Ploiesti and universities in Greece and Cyprus.

Regarding *the development of my teaching and research career*, I aim to enhance the courses I teach at the Petroleum-Gas University of Ploiesti, create new courses, laboratory work, seminar and project materials, while also modernizing the university's infrastructure by attracting funds from various national and/or European sources and expanding research opportunities with economic partners both nationally and internationally.

In scientific research, including the work dedicated to doctoral theses, it is clear that significant results are obtained through an interdisciplinary approach and strong partnerships with interested companies. This approach is intrinsic and is reflected in the content of the scientific articles I have published and the results of the research contracts I have worked on. In this context, so far, I have collaborated with all the teams within the Department of Mechanical Engineering, with faculty members from other departments of the Petroleum-Gas University of Ploiesti, with professors and researchers from universities and research institutes both in the country and abroad, as well as with specialists from the oil and gas industry and related fields. Continuing contractual collaborations with established economic partners remains a priority, alongside modernizing the university's infrastructure through funds from national and/or European sources and expanding research offers to new economic partners at home and abroad.

Innovation is another priority in developing my scientific career. In this regard, I mention the submission to OSIM, in 2023 and 2024, together with other researchers, of three patent applications.

The notable research results and collaborations with interested companies open new opportunities for formulating doctoral research topics in the field of *Mechanical Engineering*, aimed at improving the performance of technical systems and equipment.

The experience I have gained as a university professor and researcher at the Petroleum-Gas University of Ploiesti gives me the necessary competencies to supervise doctoral students and guide them effectively in completing their theses.