TOMSK POLYTECHNIC UNIVERSITY ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное
образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

Инженерная школа ядерных технологий

Направление подготовки 14.04.02 Ядерные физика и технологии

Отделение ядерно-топливного цикла

МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

Тема работы
Неразрушающий контроль покрытий SiC на подложках из Zr-1Nb, приготовленны методомселективного лазерного спекания

УДК 621.039.548: 621.039.586

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Томск – 2021г.

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School: Engineering School of Nuclear Science and Technology

Field of training (Specialty): 14.04.02. Nuclear Power Engineering

Division: Nuclear Fuel Cycle

MASTER'S THESIS

Topic of research work
Non- Destructive Evaluation of Sintered SiC on Zr-1Nb Substrates Prepared Using Selective Laser Sintering Technique

UDC 621.039.548: 621.039.586

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Section "Social Responsibility"

Position	**Full name**	**Academic degree, academic rank**	**Signature**	**Date**
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Tomsk – 2021

LEARNING OUTCOMES

Competence code	Competence name
Universal competences	
UC(U)-1	Ability to make critical analysis of problem-based situations using the systems analysis approach and generate decisions and action plans.
UC(U)-2	Ability to run a project at all life-cycle stages.
UC(U)-3	Ability to organize and lead the teamwork and generate a team strategy to achieve the target goal.
UC(U)-4	Ability to use modern communication technologies to realize academic and professional interaction.
UC(U)-5	Ability to analyze and account for cultural diversity in the process of intercultural interaction.
UC(U)-6	Ability to set and pursue individual and professional activity priorities and ways to modify professional activity based on the self-esteem.
General professional competences	
GPC(U)-1	Ability to formulate goals and objectives of the research study, select assessment criteria, identify priorities for solving problems.
GPC(U)-2	Ability to apply modern research methods, evaluate and present the results of the performed research.
GPC(U)-3	Ability to present research outcomes in the form of articles, reports, scientific reports and presentations using computer layout systems and office software packages.
Professional competences	
PC(U)-1	Ability to manage personnel, taking into account the motives of behavior and ways of developing business behavior of personnel, apply methods for assessing the quality and performance of personnel, develop and implement measures aimed at preventing industrial injuries and environmental violations.
PC(U)-2	Ability to develop and ensure the implementation of measures aimed at improving, modernizing, unifying manufactured devices, facilities and their components, developing standards and certificates, improving reliability of equipment operation.
PC(U)-3	Ability to apply basic methods, techniques and means of obtaining, storing, processing information to plan and manage the life cycle of manufactured products and their quality.
PC(U)-4	Ability to create theoretical and mathematical models describing the condensed state of matter, the propagation and interaction of radiation with matter, the physics of kinetic phenomena, processes in reactors, accelerators, the effect of ionizing radiation on materials, humans and environmental objects.
PC(U)-5	Ability to use fundamental laws in the field of nuclear physics, nuclear reactors, condensed matter, ecology in a volume sufficient for independent combination and synthesis of real ideas, creative self-expression.
PC(U)-6	Ability to evaluate prospects for the development of the nuclear industry, use its modern achievements and advanced technologies in research activities related to the development of technologies for obtaining new types of fuel and materials, radioactive waste management methods and techniques.
PC(U)-7	Ability to assess risks and determine safety measures applied for new facilities and technologies, draw up and analyze scenarios of potential

	accidents, develop methods to reduce the risk of their occurrence.
PC(U)-8	Ability to analyze technical and computational-theoretical developments, take into account their compliance with the requirements of laws in the field of industry, ecology and safety, and other regulations.
PC(U)-9	Ability to carry out independent experimental or theoretical research to solve scientific and technical problems using modern equipment, calculation and research methods.
PC(U)-10	Ability to draw up technical assignments, use information technology, standard design automation tools and application software packages in the design and calculation of nuclear facilities, materials and devices, apply knowledge of methods of ecological efficiency and economic-value analysis in the design and implementation of projects.
PC(U)-11	Ability to develop design process documentation, execute engineering design and production projects.
PC(U)-12	Ability to conduct training sessions and develop instructional materials for the training courses within the cycle of professional training programs (bachelor degree programs).

TOMSK POLYTECHNIC UNIVERSITY — ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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School of Nuclear Science & Engineering

Field of training (specialty): 14.04.02 Nuclear Science and Technology

Specialization: Nuclear Power Engineering

Nuclear Fuel Cycle Division

APPROVED BY:

Program Director

_____________ Verkhoturova V.V.

«____» ____________ 2021

ASSIGNMENT

for the Graduation Thesis completion

In the form:

Master Thesis

For a student:

Group	**Full name**
0AM9И	Elhaddad Mohammed Gomaa Mohammed

Topic of research work:

Non- Destructive Evaluation of Sintered SiC on Zr-1Nb Substrates Prepared Using Selective Laser Sintering Technique	
Approved by the order of the Director of School of Nuclear Science & Engineering (date, number):	№ 29-49/c dated January 29, 2021

Deadline for completion of Master Thesis:	05.06.2021

TERMS OF REFERENCE:

Initial date for research work: (the name of the object of research or design; performance or load; mode of operation (continuous, periodic, cyclic, etc.); type of raw material or material of the product; requirements for the product, product or process; special requirements to the features of the operation of the object or product in terms of operational safety, environmental impact, energy costs; economic analysis, etc.)	Non- Destructive Evaluation of Sintered SiC on Zr-1Nb Substrates Prepared Using Selective Laser Sintering Technique; powder of SiC ceramic was sintered on Zr-1Nb substrate by using SLS technique. Two samples were coated with 200 µm, then by using Ultrasound immersion and eddy current testing, the surface profile the coating uniformity were investigated; the products have no effect on the personal, equipment, and environment; have low cost.
List of the issues to be investigated, designed and developed (analytical review of literary sources with the purpose to study global scientific and technological achievements in the target field, formulation of the research purpose, design, construction, determination of the procedure for research, design, and construction, discussion of the research work results, formulation of additional sections to be developed; conclusions).	To review the literature To implement the objective of study To conduct the experimental studies of coating surface profile and coating integrity. To analysis the obtained results To make discussion and conclusion
List of graphic material (with an exact indication of mandatory drawings)	

Advisors to the sections of the Master Thesis (with indication of sections)	
Section	**Advisor**
One: Literature Review	Professor Lider Andrey Markovich.
Two: Materials and Methods	Professor Lider Andrey Markovich
Three: Results and Discussion	Professor Lider Andrey Markovich.
Four: Financial management, resources efficiency and conservation	Associate professor Menshikova E.V.
Five: Social Responsibilities	Associate professor Verigin D. A.

Date of issuance of the assignment for Master Thesis completion according to the schedule	05.06.2021

Assignment issued by a scientific supervisor / advisor (if any):

Position	**Full name**	**Academic degree, academic status**	**Signature**	**Date**
Professor	Lider Andrey Markovich	PhD		

Assignment accepted for execution by a student:

Group	**Full name**	**Signature**	**Date**
0AM9И	Elhaddad Mohammed Gomaa Mohammed		

TOMSK POLYTECHNIC UNIVERSITY | ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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School of Nuclear Science & Engineering

Field of training (specialty): 14.04.02 Nuclear Science and Technology

Specialization: Nuclear Power Engineering

Level of education: Master degree program

Nuclear Fuel Cycle Division

Period of completion: spring semester 2020/2021 academic year

Form of presenting the work:

Master Thesis

SCHEDULED ASSESSMENT CALENDAR

for the Master Thesis completion

Deadline for completion of Master's Graduation Thesis:	05.06.2021

Assessment date	Title of section (module) / type of work (research)	Maximum score for the section (module)
01.03.2020	Literature Review	
15.05.2020	Studying the Materials and Methods	
30.10.2020	Conduct experiments and receive results	
20.01.2021	Discuss and Analysis the output	
25.05.2021	Defense preparation	

COMPILED BY:

Scientific supervisor:

Position	Full name	Academic degree, academic status	Signature	Date
Professor	Lider Andrey Markovich	PhD, Professor		

APPROVED BY:

Program Director	Full name	Academic degree, academic status	Signature	Date
Nuclear Power Engineering	Vera V. Verkhoturova	PhD, associated professor		

TASK FOR SECTION

«FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING»

To the student:

Group	**Full name**
0AM9И	Elhaddad Mohammed Gomaa Mohammed

School	Nuclear Science and Engineering	**Division**	Nuclear Fuel Cycle
Degree	Master	**Educational Program**	14.04.02 Nuclear physics and technologies

Input data to the section «Financial management, resource efficiency and resource saving»:	
Resource cost of scientific and technical research (STR): material and technical, energetic, financial and human	Salary costs – 137813.7 rubles STR budget – **376452** rubles
Expenditure rates and expenditure standards for resources	Electricity costs – 572 rubles
Current tax system, tax rates, charges rates, discounting rates and interest rates	Labor tax – 37347.5 rubles Overhead costs – 96469.7 rubles
The list of subjects to study, design and develop:	
Assessment of commercial and innovative potential of STR	comparative analysis with other researches in this field;
Development of charter for scientific-research project	SWOT-analysis;
Scheduling of STR management process: structure and timeline, budget, risk management	calculation of working hours for project; creation of the time schedule of the project; calculation of scientific and technical research budget;
Resource efficiency	integral indicator of resource efficiency for the developed project.
A list of graphic material (with list of mandatory blueprints):	
Competitiveness analysis SWOT- analysis Gantt chart and budget of scientific research Assessment of resource, financial and economic efficiency of STR Potential risks	

Date of issue of the task for the section according to the schedule	

Task issued by adviser:

Position	**Full name**	**Scientific degree, rank**	**Signature**	**Date**
Associate professor	E.V. Menshikova	PhD		

The task was accepted by the student:

Group	**Full name**	**Signature**	**Date**
0AM9И	Elhaddad Mohammed Gomaa Mohammed		

Task for section
«Social responsibility»
To student:

Group	**Full name**
0АМ9И	Elhaddad Mohammed Gomaa Mohammed

School	**Nuclear Science and Engineering**	**Department**	**Nuclear fuel cycle**
Degree	Master program	**Specialization**	Nuclear Power Engineering

Title of graduation thesis:

Non- Destructive Evaluation of Sintered SiC on Zr-1Nb Substrates Prepared Using Selective Laser Sintering Technique	
Initial data for section «Social Responsibility»:	
1. Information about object of investigation (matter, material, device, algorithm, procedure, workplace) and area of its application	Silicon-Carbide Coating on Zr-1Nb alloy. Application area: nuclear fuel cladding. devices in nuclear applications
List of items to be investigated and to be developed:	
1. Legal and organizational issues to provide safety: Special (specific for operation of objects of investigation, designed workplace) legal rules of labor legislation; Organizational activities for layout of workplace.	Labour code of Russian Federation #197 from 30/12/2001 GOST 12.2.032-78 SSBT Sanitary Rules 2.2.2/2.4.1340-03. Hygienic requirements for PC and work with it Laser safety. General safety requirements for development and operation of laser products. GOST 31581-2012
2. Work Safety: 2.1. Analysis of identified harmful and dangerous factors 2.2. Justification of measures to reduce probability of harmful and dangerous factors	Enhanced electromagnetic radiation level Insufficient illumination of workplace Excessive noise Deviation of microclimate indicators Electric shock Laser radiation
3. Ecological safety:	Indicate impact of nuclear power plant on hydrosphere, atmosphere and lithosphere
4. Safety in emergency situations:	Fire safety;
Assignment date for section according to schedule	

The task was issued by consultant:

Position	**Full name**	**Scientific degree, rank**	**Signature**	**date**
Associate Professor Division for Nuclear-Fuel Cycle School of Nuclear Science & Engineering	Verigin D.A.	Cand.of Sc.		

The task was accepted by the student:

Group	**Full name**	**Signature**	**date**
0АМ9И	Elhaddad Mohammed Gomaa Mohammed		

Abstract

The master's dissertation work contains 100 pages with 27 figures; 26 tables and 71 references.

Keywords: Non Destructive Testing (NDT), Silicon Carbide (SiC), and Fuel Cladding.

The main goal of this research is to propose most cheaper and accurate means of monitoring defects in SiC coatings on Zr-1Nb alloy substrates for nuclear fuel cladding studies.

SiC micro-composites were deposited on Zr-1Nb alloy substrates in air and Ar atmosphere using selective laser sintering and investigated under Non-destructive techniques including immersion ultrasound testing, eddy current testing and XRD phase composition.

Both ultrasound testing and eddy current results proves SiC coating in air atmosphere having a better uniformity compared to coating done in Ar atmosphere. XRD phase qualitative and quantitative analysis reveals the formation and distribution of protective oxides such SiO2, Al2O3, Y2O3 which could protect the underlying layer from atmospheric contaminants. Ultrasonic immersion technique and eddy current testing have the potential to be used for in-service inspection of SiC coatings on Zr alloy tubes to ensure the structural integrity in this particular design of cladding tubes in the nuclear power industry.

List of Abbreviation

NPPs..Nuclear power plants

LWRs... Light water reactors

Zirlo..Zirconium low oxidation

Zr..Zirconium

SiC..Silicon carbide

NDT..Nondestructive testing

PWR... Pressurized water reactor

BWR...Boiling water reactor

HCP..Hexagonal close packed

LOCA... Loss of coolant accident

HTGRs... High temperature gas cooled reactor

SLS...Selective laser sintering

UT.. Ultrasonic testing

CRT..Cathode ray tube

EC...Eddy current

IR..Infrared imaging

TBC..Thermal barrier coating

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Introduction

The largest part of the commercial NPPs are light water reactors. LWRs have demonstrated to be fruitful, producing free emission electricity at low cost comparing to that of coal and fossil fuel-based plants. There are 359 LWRs worldwide operate with a capacity of 338 GWe3 which represent 87% of all nuclear electricity and 14% of the worldwide total electricity [1,2].

Currently LWRs utilize zirconium alloy as a fuel cladding material. Zirconium alloys has gained a long-term application in the nuclear industry [3,4] due to some unique characteristics including low thermal neutron absorption cross section, high corrosion resistance and appropriate mechanical strength [5].

Since 1990s, average fuel burn-up has been doubled and power uprates of the existing nuclear power plants and cycle lengths have expanded [1]. Therefore, there has been several modifications of the zirconium alloys such as the Zirlo (USA) [6], M5 (France), and the Russian E-series alloys to improve their properties against these harsh operational environment, however issues including high temperature oxidation and hydrogenation of zirconium alloy fuel cladding materials still remain a hurdle and requires intensive research to minimized those challenges [7].

Fuel system and core structures in current light water reactors are vulnerable to catastrophic consequences in the event of loss of coolant or active cooling, as was evidenced by the March 2011 Fukushima Nuclear Power Plant accident [8,9,10]. This vulnerable is attributed mainly to rapid the oxidation kinetics of zirconium (Zr) alloy in a water vapor environment at exceptionally high temperatures, which results within the production of explosive hydrogen [10,11].

The work scope of LWRs focuses on fuel system component outside of the fuel pellet permitting for change of the existing zirconium-based clad system through coatings by adding a ceramic layer, or complete replacement of the fuel cladding. Fuel cladding material selection is based on many design limitations, such as neutron absorption cross section, service temperature, mechanical strength, toughness, neutron radiation resistance, thermal expansion, thermal conductivity, and chemical compatibility [8,9,10,11]. There are several researches ongoing on advanced cladding concepts such as Sic [12,13], liquid metal bonded hydride fuel [14], high conductivity metallic fuel, and composite fuels [1] towards the development of future generation cladding components of light water reactors.

According to Jin D. et. al, 2016, depositing SiC coats on Zr-alloys demonstrates a promising method to improve corrosion [15]. It is also evidenced that SiC coatings helps to establish good oxidation resistance even at high temperatures, and demonstrates high level of hardness [16,17]. Investigations on the mechanical properties of SiC deposited with magnetron sputtering on zircaloy-4 substrate reveals that, the hardness and the elastic modulus of the deposited film decreases with increasing working pressure [18]. On this note, silicon carbide is the leading candidate of a new approach coupled with several investigations of coating SiC on zirconium alloy involving the Selective Laser Sintering technique.

Goal and Tasks of the Research

The main goal of this research work is to propose the most applicable and compatible NDT techniques for monitoring defects in sintered SiC coats on Zr-1Nb substrates.

There are three main categories of tasks associated with the research as stated below;

Theoretical and practical Understanding of the coating technique.

Understanding the various strengths and weaknesses of using NDT techniques in monitoring defects in ceramics (SiC).

Investigating with NDT techniques to control defects in the sample

Analyzing and drawing conclusions on the experimental results.

Chapter 1 - Literature Review

1.0 Standard Zirconium Based Alloy

Within the 1950s improvement of nuclear propelled naval submarines in united states, prompted the selection and improvement of a cladding material having low neutron absorption cross-section, high strength and good corrosion resistance.

Six decades of alloy improvement has produced tailored alloy chemistries and handling strategies that provide a satisfactory degree of corrosion resistance under pressurized or boiling water reactor (PWR or BWR) conditions whereas restricting irradiation growth and creep to the extent that these phenomena are now frequently insignificant to reactor operation.

The attractive properties of zirconium alloys render them well suited for utilize as nuclear fuel cladding and structural components in conventional LWRs. The satisfactory performance of zirconium alloys is challenged once a move is made from an environment related with typical operating conditions in LWRs to reactor accident scenarios.

A variety of accident sequences can result during loss of cooling inside the core and that will inevitably drive up the fuel temperature and expose the cladding to a high-temperature steam environment [19,20].

1.0.0 Corrosion of Zirconium Alloy

In general Zirconium alloys are highly resistant to corrosion, however they are not totally immune to oxidation in the harsh conditions that exist inside the nuclear reactor. In both Boiling Water Reactors (BWRs) and Pressurized Water Reactors (PWRs) the corrosion issues for zirconium alloys are unique due to the differences in operating conditions and alloys employed. PWRs currently used Zr-Nb cladding (Zirlo and M5), while BWRs utilize Zr-2.

The main differences between BWRs and PWRs types which affect corrosion are coolant boiling in BWRs, high concentration of hydrogen in PWR coolant, high concentration of oxygen in BWR coolant, and PWR operating at higher temperature. The design-limiting issue in LWRs is corrosion and it is extremely complex, and still remains poorly understood [19,20].

1.0.1 Oxidation of Zirconium Alloy

The formed zirconium oxide layer in oxidation kinetics of zirconium alloys remains coherent. Since the oxidizing species is water (steam), the response produces a significant amount of hydrogen gas.

The heat production rate due to the oxidation reaction with cladding becomes significant at temperatures above 1200ºC. At this point the oxidation reaction has the potential to exceed decay heat production in the fuel and become the main source of fuel temperature rise. This reaction quickly leads to increase the fuel temperature and results in oxidation of the entire cladding, as a result converting the clad to the brittle ceramic material ZrO2.

Rapid growth of oxide layer and increasing oxygen solubility in the β-Zr phase at temperatures above 1200ºC that leads to loss of ductility in the cladding. Therefore, the maximum limits of cladding temperature to 1204ºC (2200ºF). Accordingly, the maximum extent oxidation in the cladding is limited to 17% of its initial thickness [19,20].

1.0.2 Hydrogen Pick-up

Hydrogen pick-up is the absorption of hydrogen generated during the low rate surface corrosion process into zirconium-based alloys. Free hydrogen ions generate as a result of zirconium oxidation by water, which can then permeate into the zirconium alloy. At LWRs operating temperatures the solubility of hydrogen is extremely low as a result, hydrogen precipitates out as hydrides. These hydrides are pernicious to the corrosion properties, have a higher coefficient of thermal expansion therefore affecting local dimensional stability and stress and the mechanical properties of the zirconium alloys.

The hydrides accelerate and then migrate to higher stress area, which can result in deferred hydride cracking. Hydrides also cause increasing in uniform corrosion rate, however, the mechanism for this increase is not well understood. Additionally, due to the low density of the hydrides, hydrogen pick-up causes local swelling in the zirconium alloys [19,20].

1.0.3-Dimensional Stability

Hydride volume changing, irradiation growth due to HCP structure and irradiation creep (thermal creep is insignificant at operating temperatures) are the main reasons of dimensional instability in zirconium alloys.

Irradiation creep is critical to the interaction of the cladding with the fuel pellets. Initially a gap exists between the fuel pellet and cladding, then the cladding creeps down to close this gap. At higher burn-ups the gap begins to reopen due to fission gas pressure. The limiting mechanical property for many accident scenarios, such as a LOCA, due to the high temperatures seen during these accidents is creep. Zirlo and M5 have improved irradiation and thermal creep properties, allowing a larger safety margin during accident scenarios [19,20].

1.1 Advanced Cladding Technologies

Advanced cladding technologies inspected are comprised of coatings on existing zirconium-based cladding, hybrid ceramic/metal cladding, or total replacement of the conventional nuclear fuel cladding. The potential benefits of each of these innovation categories is varied, from simply reducing the rate of fretting failure to permitting operation at higher temperatures with larger safety margins. Table 1.1 summarizes the potential benefits and drawbacks of specific technologies.

Table 1.1: The potential benefits and drawbacks of specific technologies.

Type	Technology	Potential Benefit	Potential Drawback
	SiC	- Adequate thermal properties and compatibility with fuel. - use in higher heat rate applications. - Retains the small/no fuel clad	- Cannot withstand the same temperature of fully SiC clad. - Yield strength limited (650 o C).

Zr-alloy Coatings		gap characteristic yielding good overall thermal conductivity of zirconium cladding.	- - Minimal development experience
	Ti3AlC2	- High melting point (2000 o C). - High thermal conductivity (40 W/m-K). - High strength and fracture toughness, corrosion and oxidation resistant.	- Minimal development experience. - Oxidation Limited (1450 o C)
	Ti3SiC2	- High melting point (2000 o C). - High thermal conductivity (37 W/m-K). - High strength and fracture toughness, corrosion and oxidation resistant.	- Minimal development experience. - Oxidation Limited (1000 o C).
	General coating technologies	- Easy application of coatings onto Zr-based alloys. - maintains same base material as current cladding (no hermeticity issues).	- Coatings could be scraped off during fuel assembly. - localized region of exposure could cause rapid oxidation of underlying Zr-based alloys.
Hybrid	SiC CMC Zr-4	- High temperature strength. - Low chemical reactivity. - no exothermic reaction. - very hard material prevents fretting failure. - retains the small/no fuel clad gap characteristic. Zr-4 inner tube provides hermitic seal to fuel.	- Hydrogen generation from the inner Zr-4 tube under LOCA. - potential hydrogen embrittlement. - Bonding techniques between SiC CMC and Zr-4 tubing need to be developed and tested.

1.2 Silicon Carbide

Silicon carbide (SiC) is promising for improved performance in certain areas under LWRs core conditions, especially under conditions where properties of zirconium-based alloys could be significantly degraded, such as LOCA event. Silicon carbide-based cladding may provide larger safety margins in the case high burnup capability (>62 MWd/kgU) with longer cycle lengths or uprated operation (higher heat fluxes).

Silicon carbide-based cladding may also be used for advanced reactor concepts where high fuel coolant temperatures such as superheated coolant or high-temperature gas reactors where physical properties of materials would be degraded. Unlike zirconium-based alloys, Sic-based materials would retain its strength and withstand the creep up to 1300 ^{0}C and remains viable to even higher temperatures until onset of fuel-clad reaction. Silicon carbide has been proved to be stable at extremely high irradiation doses after the initial irradiation effects, which include swelling and changes to strength and thermal conductivity, are saturated after a few months of typical operation. There is also a neutronic benefit, where Sic materials parasitically has lower absorption cross section than Zr-based alloys, also has very low activation and contributes a little more to neutron moderation [20].

1.2.0 Structure and Properties of SiC

Silicon carbide is a covalent compound with low density (3.2 g/cm^3), high strength, good thermal stability, and high theoretical thermal conductivity (490 W/m K) [21,22,23]. The interesting feature of silicon carbide is the ability to remain stable even at temperatures beyond 1400 ^{0}C and with a Young modulus above 400 GPa earns it an excellent dimensional stability which predestined SiC a solid construction material [24].

Silicon carbide also have a unique corrosion resistance even at high temperatures and a reasonable thermal neutron cross-section similar to that of zirconium [24]. Stoichiometric and crystalline SiC has good irradiation resistance and low induced-activation. Therefore, SiC ceramic and SiC-based composites, especially continuous SiC fiber-reinforced SiC matrix composites (SiC/SiC [24]), are promising candidates as nuclear structural materials. Therefore, there are several researches ongoing on SiC coating towards development the future generation cladding components of light water reactors where SiC and SiC/SiC composites are considered to provide outstanding passive safety features in beyond-design-basis severe accident scenarios [25]. One of the challenges of working with silicon carbide is that it can crystallize into many different polymorphs, the most common being the 3C (β-SiC), and the hexagonal (α-SiC): 2H, 4H and 6H phases [26].

Silicon carbide crystallizes in numerous polytopes where the total number likely is more than 200. Some of the characteristics for the polytypes are shown in Table 1.2 and the structure and the atoms arrangement are demonstrated in Fig. 1.2.0.1 [27]. The SiC polytypes content is defined by perpetration conditions and the impurities. It has been proved that the cubic polytypes 3C-SiC is more stable comparing with other hexagonal polytypes up to temperature of 2100 °C [28].

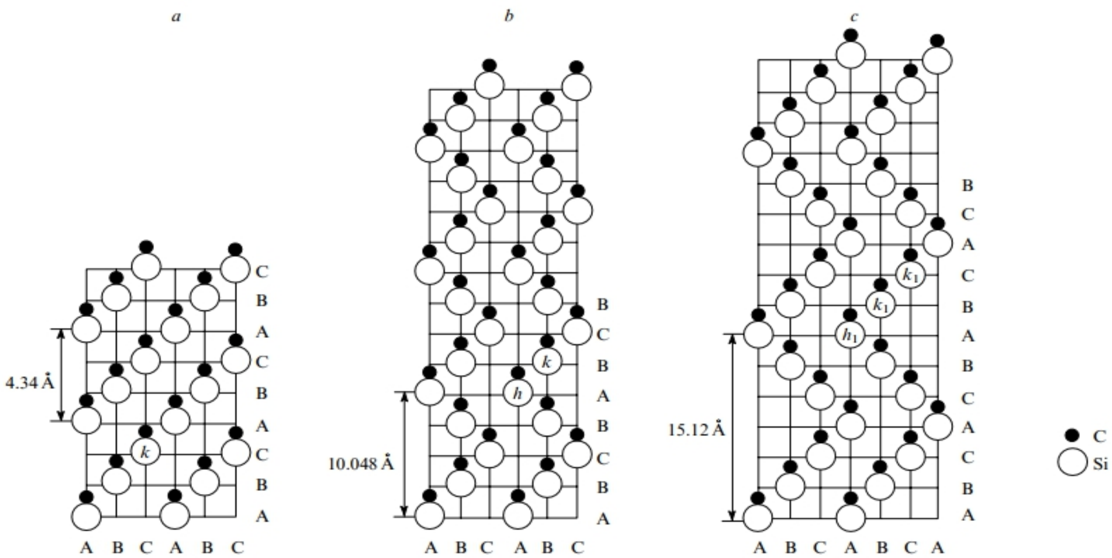

Figure 1.2.0.1 – Positions of carbon and silicon atoms (1120).7 (a) 3C-SiC, (b) 4H-SiC, (c) 6H-SiC.

Table 1.2 : The main physical/chemical properties of the most widespread SiC polytopes [27].

Property	Polytypes			
	3C-SiC (β–SiC)	2H-SiC (α–SiC)	4H-SiC (α–SiC)	6H-SiC (α–SiC)
Space group	F43m	P63mc	P63mc	P63mc
Hexagonally (%)	0	100	50	33
Stacking order	ABC	AB	ABCB	ABCACB
Lattice constant a	0.435890.43596	0.30753-0.3081	0.3070-0.3081	0.3073-0.3081

(nm)				
Lattice constant c (nm)	–	0.5031-0.5048	1.0053-1.008	1.51092-1.512
Density (g/cm3)	3.215	3.219	3.215	3.212
Band gap	2.39	3.33	3.26	3.0
Thermal conductivity ($W\ Cm^{-1}\ K^{-1}$)	3.6	–	4.9	4.9
Electron mobility ($Cm^2V^{-1}\ s^{-1}$,300K)	≤1000	–	≤850	≤450
Hole mobility ($Cm^2V^{-1}\ s^{-1}$,300K)	≤40	–	≤120	≤100
Electrical resistivity (Ω cm)		$10^2 – 10^3$		

1.2.1 SiC Applications in Nuclear Technology

Silicon carbide ceramic materials have many attractive properties such as high strength, stiffness, good oxidation, corrosion resistance and thermal shock resistance [29], and high thermal conductivity [29,30,31]. Silicon carbide ceramic materials are either being utilized currently or under research consideration for using in a wide range of applications such as aerospace, nuclear energy process and transportation industries [31].

Silicon carbide ceramics and their composites have been extremely investigated for their applications in fission and fusion energy systems because their exceptional properties such as extremely high temperature properties, irradiation tolerance, inherent low activation, and other exceptional physical and chemical properties [32-34].

Silicon carbide ceramic is being used as a coating layer in TRISO fuel particle as shown in figure 1.2.1.1. Also Sic/Sic composites can be used in or out of the core, including control rod sheath and heat exchanger components in high temperature gas cooled reactor (HTGRs) [32,33,35,36]. Recently lots of efforts have been done to apply Sic/Sic composites in the fuel cladding of light water reactor (LWR), guide tubes and channel boxes for boiling water reactor (BWR) fuel assembly [32,37,38].

Sic/Sic composites have lots of advantages over the current zirconium alloys such as slightly lower neutron absorption cross section and higher burn up rate therefore its better in terms of neutron economy. As well as the high temperature of Sic ceramic may allow to operate the clad material at higher temperature and exhibit better mechanical properties for fuel-clad interaction. Also Sic cladding is expected to decrease the vibration including fretting wear and minimize the production of hydrogen during severe conditions [39,40].

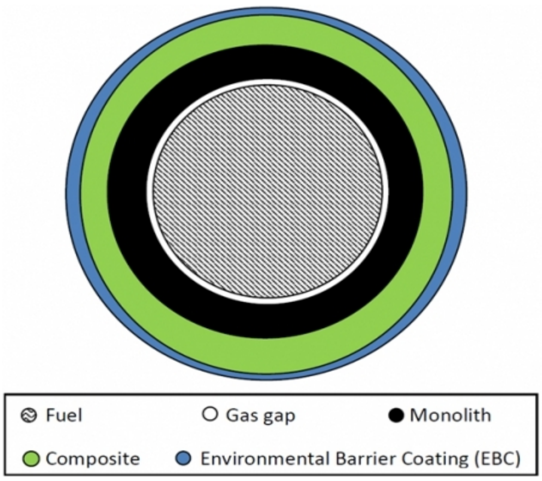

Figure 1.2.1 1 – Structure of Triplex SiC Composite Cladding

1.3 SLS Technique

SLS was invented by Carl R. Deckard and Joseph J. Beaman in the 1980s at the University of Texas [41]. The selective laser sintering (SLS) technique is a powder bed fusion technique in which a laser beam is used to fuse powder materials selectively according to the digital design of the built part. [42]

Selective laser sintering (SLS) is an addictive manufacturing process in which three-dimensional printing is used to fabricate and design material by joining and solidifying under computer manipulation [43,44]. Selective laser sintering is highly applicable and durable manufacturing technique. It is capable of producing highly complex geometries. The method produces high-heat and chemically resistant applications. Despite the complexity of the SLS system, it is beneficial in managing time and cost of production. It is also possible to design and build large platforms for mega structural fabrications. In the course of the building of the print, automatic filling of the hollow spaces with the unused powder simultaneously takes place, hence making the SLS as shown in figure 1.3.1 deposition self-supporting and maintaining a huge degree of freedom in the design process [45].

The unique feature of laser processing of ceramics is that, at a specific time the interaction between ceramic powder and the laser beam only a tiny amount of laser energy is absorbed, some is transmitted and some is reflected. In order to evaluate the laser efficiency processing, it is necessary to quantified the intensity of the incident laser beam that coupled to the sample. This efficiency is described by the so-called absorption coefficient. There are also other quantities used to evaluate the laser processing are called reflectance and transmittance. These quantities are described by following equations. The absorption coefficient [45], A, is given by:

$$A = 1 - T - R \qquad (1.2.1)$$

A = (Absorption energy inside the sample)/ (Total incident energy) while reflectance, R, is: R = (Reflected energy from the sample) / (Total incident energy) and transmittance, T, is defined by: T = (Transmitted energy through the sample)/ (Total incident energy)

1.4 Non – Destructive Testing

Nondestructive techniques (NDT) have a long-term operation experience, with technological advances therefore rapid developments in instrumentation encouraged. NDT is widely applied in power plants, aerospace, nuclear industry, military and defense, storage tank inspection [46].

The structural integrity of ceramic coatings is of critical importance in meeting their intended performance and durability requirements. The integrity is adversely affected by the presence of defects, some of which may be in the as-deposited coatings as a result of processing aberrations, whereas others develop in use.

Defect characteristics of ceramic coatings include mechanical damage, contaminated interfaces, surface bonding, transverse and longitudinal cracks within the coatings, density and thickness variations, internal oxidation, oxidation and corrosion accumulation at the interface, and excessive porosity and inclusions. In addition to some of these defects, ceramic coatings may exhibit discontinuity in deposition, miss-orientation of columnar structures, and infiltration by foreign materials. Whereas statistical process development and stringent quality control may eliminate the majority of these defects in as-processed coatings, the others need to be identified by routine destructive and nondestructive testing (NDT).

Destructive testing tends to be expensive. Use of NDT techniques, therefore, is very attractive. However, in contrast to bulk structural alloys, the number of NDT techniques successfully applied to coatings is very limited. NDT techniques belong to one of two categories. The first category is based on the response of a material to a stimulus from the environment in which it is being tested or the response of existing defects in the material to externally imposed stimuli for example, the ultrasonic NDT technique, in which an external stimulus in the form of an ultrasonic pulse is imposed on the material. The second category is not dependent on the stimulus. This category is illustrated by radiography, which does not involve significant interaction with the material other than absorption or transmission [47]. For the purpose of the research work, a number of NDT techniques which are compatible with ceramic coatings are reviewed next.

1.4.0 Ultrasonic Testing (UT)

Ultrasonic testing is one of the most established NDT techniques as it is applicable to most materials. The fundamental understanding of ultrasonic testing is based on the transformation of a voltage pulse into an ultrasonic pulse by a transducer. The transducer is positioned on the specimen and transmitted pulses (ultrasonic waves) travel through the object. The ultrasonic frequency, generally in excess of 20 kHz and typically between 0.1 and 25 MHz, is such that to generate elastic waves in the solid material [48].

The elastic waves propagate through the sample, strike defects including surfaces and interfaces, and undergo reflection known as echoes. The probe detects all waves and displays them on an oscilloscope as a spectrum of echoes arriving at different times. Analysis of the spectrum provides indication of shape, size, and location of the defects. Depending on the dimensionality of the scans, the evaluation method is designated as UT (ultrasonic testing) A, UT B, or UT C type scans.

The UT A scan, usually used to measure thickness based on the incident signal and the signal reflected from a parallel surface, provides a one-dimensional display. The B scan consists of parallel sets of A scans, and the UT C scan provides a two-dimensional display of distribution of defects [47,48].

Three basic methods of ultrasonic inspection include the normal incident pulse-echo, angle beam pulse echo and through-transmission method. In all cases, the signals captured are transformed back into electrical pulses and are displayed on a cathode ray tube (CRT) [47].

1.4.0.0 Material Compatibilities of Ultrasonic Defect Testing

The ultrasonic NDI technique is applicable to metallic, nonmetallic, dielectric, magnetic, and nonmagnetic materials. Inclusions, slag, and porosities are some of the defects detectable in ultrasonic testing. Corrosion can be detected through thickness measurement. While there are a few parameters that influence the flaw sensitivity, the minimum detectable defect size is highly dependent on the frequency of the probe [47].

According to Raj et al. 2002, the wavelength, which varies inversely with frequency, is a direct function to the detectability of a defect. The most advantageous detection scenario is when the defect is larger than the wavelength. With an increase in the wavelength, the possibility of detection decreases significantly. With the use of a particular frequency probe, it has been established that defect size of the order of half the wavelength can be inspected.

Ultrasonic testing has been proven to be an efficient technique for the detection of discontinuities and measurement of mechanical properties of material references [49]. It has the potential for monitoring and testing of defects present as each layer is being built during powder bed fusion processes.

The use of ultrasonic testing has been examined substantially for castings. It has, however, been hindered by the surface roughness for the detection of defects near the surface. According to Palanisamy et al. 2007, tested aluminum sample castings using ultrasound with frequencies ranging from 5 to 20 MHz Results have shown that the defect signal amplitude decreases drastically when the surface roughness of the sample castings is above 50 µm. For surface roughness above 150 µm, the defect signal amplitude becomes negligible for all frequencies.

Thickness and elastic properties of ceramic and metallic coatings have been measured by a modified ultrasonic NDT technique that generates elastic surface waves, known as Rayleigh waves, with specially prepared focusing transducers [50]. Thickness, coating density, and micro hardness of thermal spray coatings can be measured or estimated by the ultrasonic NDT technique. The thickness is measured by introducing an ultrasonic signal into a coated component from a transducer. Time delay between signals reflected from the coating surface and the coating substrate interface is recorded on a CRT display. Multiplying this delay by the velocity of sound in the coating gives twice the thickness of the coating [47].

1.4.0.1 Ultrasonic Technique Working Principles

Ultrasonic Testing uses sound wave with high frequency of sound energy to conduct the investigations and detect the defects. Ultrasonic inspection can be used for detection and evaluation the flaw, measuring the dimensions, characterizations of the material, and more. To understand the general inspection principle, a typical pulse echo inspection configuration as illustrated below.

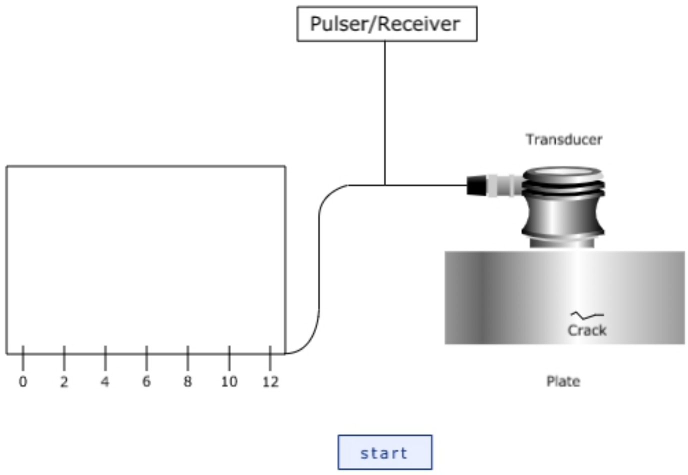

Figure 1.4.0.1.1 – Typical Pulse Echo Inspection

The speed of sound wave varies depending on the medium encountered. In the process, the waves are affected by the density of the medium and the elastic characteristics as well, because different types of sound wave travels at different velocities. Moreover, all types of waves have an associated wavelength. The equation 1.1 below represents the relation existing between wavelength, velocity of sound and their frequency.

$$\lambda = \frac{c}{f} \qquad (1:1)$$

Where c, f, λ represents velocity, frequency and the wavelength of sound respectively. A limiting factor that controls the amount of information that can be obtained from the behavior of wave is the wavelength. Therefore, in ultrasonic defect detection, the lowest wavelength limit for the detection of the smallest flaw visible is of magnitude of one-half the wavelength. A flaw of wavelength smaller than this will be invisible. One wavelength (λ) sets the minimum theoretical thickness that can be measured during an ultrasonic thickness measuring process.

There exists a direct proportionality dependence of distance traveled by a wave of a specific energy and frequency through a material. Hard and homogeneous materials are better in transmitting sound waves through them more efficiently than those materials with soft and heterogeneous or granular characteristics.

There are three main factors that controls distance travelled by sound wave through a specified medium. These factors include attenuation, beam scattering and beam spreading. When beam travels through a medium, its leading edges widens, hence, the energy involved with the wave propagation distributes over a larger area and finally results in the dissipation of the energy. Therefore, attenuation is defined as the loss in energy as sound is transmitted through a medium or the degree to which energy is absorbed as the wave front moves through a medium. Scattering occurs when sound energy is randomly reflected from grain boundaries and similar microstructures. The spreading of beam increases as frequency decreases and this result to reduction in the effects of attenuation and scattering as well. During ultrasonic testing, transducer frequencies are adjusted to the medium involved in order to optimize their variables.

1.4.0.2 Reflection at a Boundary

When boundaries are approach by sound and as it travels through a medium or a material, part of the energy is reflected back and a portion transmitted through. The quantity of energy reflected also known as the degree of reflection or reflection coefficient is linked to the relative acoustic impedance of the two materials. Sound travels through a material based on the influence of sound pressure. Therefore, the acoustic impedance (z) of a material is the product of its density (ρ) and the acoustic velocity (V) as indicated in the equation 1.2 below.

$$Z = \rho V \quad (1.2)$$

Hence, for every two materials, the reflection coefficient in percentage wise of the incident energy can be computed using the equation 1.3 below.

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1} \quad (1.3)$$

R stands for the reflection coefficient in percentage, Z_1, and Z_2 represents acoustic impedance of first and second medium respectively. In metallic and air boundaries which is mainly encountered medium in ultrasonic defect determination applications is capable of given a 100% reflection coefficient. This actually means that all the sound wave energy that is transmitted and hits a crack or another kind of discontinuity along its path is reflected completely.

1.4.0.3 Reflected and Refracted Angles

When sound is transmitted in a perpendicular pattern strikes a surface, it is also reflected in the same straight path. When sound beam strikes a surface at an angle of same medium, reflection also occurs in that same angle. Therefore, the angle of incidence and reflection remain the same as stated in the law of reflection in same medium. Moreover, sound travelling from one medium to another bends in accordance to Snell's law of refraction. Therefore, a sound beam travelling in a straight path will continue in the same direction, whiles a beam traveling around a boundary at an angle will be bent according to the equation 1.4 below.

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{V_1}{V_2} \tag{1.4}$$

Where θ_1 and θ_2 denotes the incident angle in the first medium and the refracted angle in the second medium. Also, the V_1 and V_2 represents the velocity of sound in the first medium and in the second medium respectively.

1.4.0.4 Ultrasound Transducers

In general, a transducer is a device that is capable of converting an energy in form of a signal to another signal of energy, hence, the process involved is known as transduction. Therefore, ultrasound transducers convert electrical energy into high frequency sound energy and vice versa. Transducers for defect detection is mostly made of an active element which is composed of a piezoelectric ceramic, polymer or composite. Triggering this element with a high voltage electrical pulse makes it vibrates across a specific spectrum of frequencies which generates a burst of sound waves. However, when an incoming sound wave strike the detector, it causes it to vibrate and generates electrical pulse using the transducer principles of operation.

Usually, the very surface of the transducer element is mostly covered with a wear plate which protects the element from damages.

Moreover, the exterior is also bonded to backing material that mechanically dampens vibrations once the sound generation process is complete. A gel or a thin layer of lubricant is normally used between the test piece and the detector. This is done due to the fact that sound energy at ultrasonic frequency level are incapable of travelling through a gaseous medium effectively.

There are five main types of transducers used for ultrasonic testing. The first one known as the **contact transducers** are used in close contact with the test object. This kind of transducers introduce sound energy perpendicular to the contact surface. This transducer is used for locating porosity, voids, cracks or failure characterized in composite materials which are also known as delamination. This contact transducer is also used in measuring thickness of test piece. The figure 1.4.0.4 a below represents a typical contact transducer.

Figure 1.4.0.4.a - a typical contact transducer

The next one is known as the **angle beam transducers**. This type of transducers is used in addition with plastic or epoxy wedges. Together, they are used to introduce shear waves or longitudinal waves into a test material at a directed angle with reference to the surface. The angle beam transducer is the mostly used in inspecting welding perfections. The figure 1.4.0.4 b below is a typical example of the angle beam transducer.

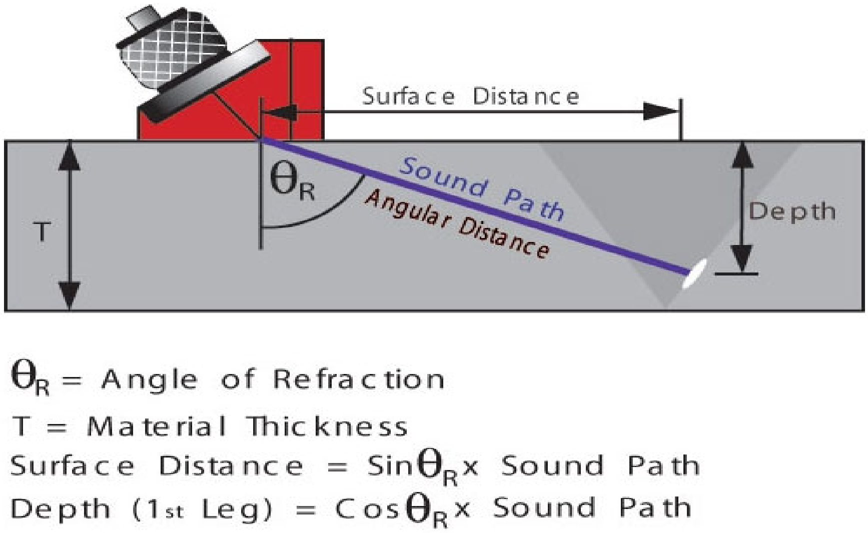

Figure 1.4.0.4.b – A typical angle beam transducer

The third type of the ultrasound transducer is known as the delay line transducer. This kind of transducer incorporates a short plastic waveguide also known as the delay line between the active element and the test piece. They are switched in conducting testing under high temperatures where the delay line protects the active element from thermal damage. They are used also in improving near surface resolution, as depicted in the figure 1.4.0.4 c below.

Figure 1.4.0.4.c – A Typical Delay Line Transducer

The fourth one is known as the **immersion transducer**. This kind of ultrasound transducer are designed to channel sound energy or waves into the test piece through a water column. They are mainly applied in automated scanning. An immersion transducer is a single element longitudinal wave transducer with a ¼ wavelength layer acoustically matched to water. This kind of transducers are designed to transmit ultrasound in circumstances where the test piece is partially or wholly immersed in water. This encourages a uniform and fast sampling technique for quick scanning of parts as shown in the figure 1.4.0.4 d below.

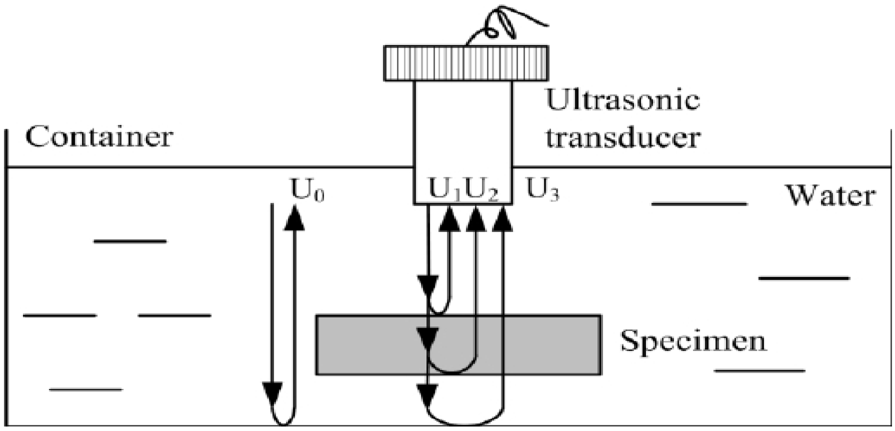

Figure 1.4.0.4.d – A typical immersion transducer

The final type of the popular ultrasonic transducers is known as the **dual element transducers** since it makes use of separate transmitter and receiver elements in a single assembly. This kind of transducer is applicable in rough surfaces, coarse grain materials, and detecting porosity. They can be used in a high temperature condition as well. The figure 1.4.0.4 e below is a typical representation of an immersion transducer.

Figure 1.4.0.4.e – A typical dual element transducer

1.4.0.5 Advantages and Disadvantages of Ultrasound Testing

Ultrasonic testing is a very robust and versatile technique which has been extensively applied in industries for NDT. Out of all the NDT techniques, only ultrasonic and X-ray methods are efficient in detecting considerable number of subsurface defects in materials. Contrary to X-ray methods, ultrasonic testing does not constitute to environmental or health risks. Both contact and non-contact ultrasonic testing approaches are available.

Ultrasonic test probes can be applied for the testing of complex parts. Ultrasonic inspection is ideal for testing of all types of materials ranging from biological to polymer to ceramic [51].

According to Raj et al. 2002, Testing can be performed on specimens with only one accessible surface, unlike in radiographic techniques, where two opposite sides of the specimen must be accessible.

Ultrasonic testing, like other NDT methods, has some disadvantages. Obtaining quantitative information of the specimen and the accurate interpretation of results require a skilled operator. Typically, planar cracks with length that lie parallel to the direction of ultrasonic wave travel are not detectable. In addition, ultrasonic testing equipment can be expensive [51].

1.4.1 Eddy Current

Eddy current testing is based on Faraday's law of electromagnetic induction and defined as oscillating electrical currents induced in a conductive material due to electromagnetic induction, by an alternating magnetic field [51]. An alternating current, usually with frequency ranging from 1 to 2 kHz, flows through a primary (excitation) coil to produce an alternating (primary) magnetic field as shown in Figure 1.4.1 a.

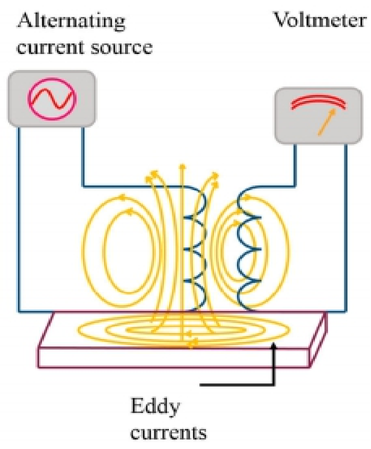

Figure 1.4.1.a – Probe response in the absence of conductive material

When the primary coil is in close proximity to the electrical conducting surface of a metallic material, an eddy current is induced in the material due to electromagnetic induction as illustrated in Figure 1.4.1 b. The presence of defects in the material causes perturbation to the flow of eddy current, which in turn, produces a secondary magnetic field that opposes the primary field.

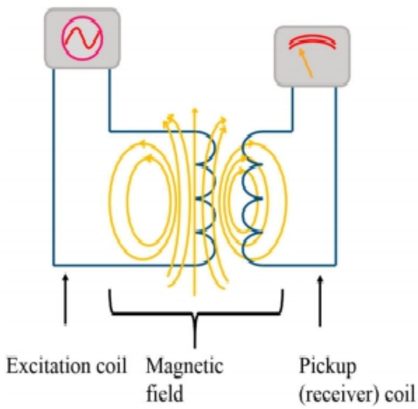

Figure 1.4.1.b – Probe response in the presence of conductive material

The electrical conductivity, magnetic permeability, and geometry of the material are the main drivers affecting the magnitude of the eddy currents, and hence of the secondary field. For an ideal conductor, there will be a complete cancellation between the primary and secondary field. Response signals are represented in a range of formats, all of which indicates impedance changes in the receiver coil. In many application-specific systems, changes in the amplitude of the electromotive force are computed while the results reflect the parameters of interest, such as the thickness of the coating [51].

Conductive specimens with defects such as cracks and inclusions, which cause a change in the output impedance, are detectable by eddy current testing. Surface and subsurface corrosion can be distinguished. Variation in the thickness of coating can be investigated based on the differences in conductivity between the conductive specimen and the coating. This technique does not require the removal of surface coatings such as paint and anodized films for inspection [53]. The sensitivity of discontinuity detection is dependent on the material, the type of defect and its orientation, the depth of the defect, and the surface quality of the material. According to Raj et al. 2002 Eddy current testing can be used to inspect conductive parts of thickness up to 6 mm with adequate sensitivity.

A major advantage of eddy current testing over ultrasonic technique lies in it being a non-contacting method, which enables automated high-speed assessment. In addition, surface preparation of the test specimen is not required when employing this technique. Eddy current testing is one of the few inspection techniques that are suitable for high-temperature applications [51]. In the aircraft industry, this technique can be used to measure the conductivity of heat-treated aluminum components in quantifying the hardness and tensile strength of the part. According to Jochen et al. 2003, Measurements can be taken during heat treatment instead of after, offering more information about the process.

The main limitation of eddy current testing is that only electrically conductive materials can be tested [51]. The probe used in eddy current testing does not solely respond to the desired material characteristics such as discontinuities and conductivity, but also detects unwanted signals related to conductivity and magnetic permeability, leading to increased complexity in results interpretation. Hence, sophisticated algorithms and professional operator training are required to segregate the desired and unwanted signals.

1.4.2 Frequency Scanning Eddy Current Technique

The Frequency scanning EC is a variant of the process described earlier in which the eddy current probe operates within a range of frequency, typically between 100 kHz and 10 MHz Impedance is measured as a function of the frequency.

According to Antonelli et al., 1997, the applicability of this technique to coatings has been demonstrated in measuring the thickness of anti-fretting coatings on Ti6Al4V alloy gas turbine compressor blades and MCrAlY coatings deposited on turbine blades made of Ni base super-alloy IN738. The capability of this technique has been demonstrated in measuring the metallic and ceramic coating thickness within 2mm, determining electrical conductivity of metallic coating and surface roughness.

1.4.3 Infrared Imaging

Thermal imaging, also known as thermal wave imaging or infrared (IR) imaging, is a very attractive NDT technique for heat-insulating materials and has been evaluated by Ferber et al., 2000, for monitoring damage accumulation in thermal barrier coatings. The technique requires establishing a temperature gradient across the TBC-coated sample subjected to prior cyclic thermal exposure and monitoring the temperature of the ceramic coating surface with an IR camera. The temperature gradient may be established by placing the thermally cycled sample on a hot plate so that heat flows across the thickness. The damage created in the TBC due to cyclic thermal exposure generally consists of micro cracks. These reduce heat transfer to the surface, which progressively appears cooler with continued thermal cycling.

1.4.4 Pulse Echo Thermal Wave Infrared Imaging

A variant of the IR imaging technique is the pulse echo thermal wave IR imaging [54]. The basic premise of the process is that defects generated in a TBC locally change the thermal conductivity. A flash lamp delivers a pulse of heat to the surface of a TBC-coated sample. The areas with underlying defects appear hotter because of slower dissipation of heat by conduction. The temperature also decays slowly. An IR camera connected to computers maps the temperature distribution. The analysis of the distribution of temperature and decay times provides.

This technique has been found to detect various types of flaws in the presence of delamination at the ceramic bond coat interface [55]. An example of damage assessment of TBCs by the pulse echo thermal wave IR imaging technique is described by Chen et al. 2001. TBC-coated samples, consisting of 8YSZ (yttria-stabilized zirconia) ceramic, deposited by EB-PVD on bond-coated Rene N5 single-crystal superalloy, were thermally cycled in a furnace between 392 F and 2150 F. The cycle consisted of 9 min to heat up, 45 min hold at high temperature, and 10 min to cool down. Both thermal wave image and surface temperature profiles were measured on the TBC surface as a function of time. Progressively, the amplitude of the thermal signal increased until the TBC failed. The increase in thermal wave amplitude is attributed to the reduction in thermal conductivity due to continued damage accumulation. The reduction more than compensates for any increase in thermal conductivity due to ceramic sintering. The data show that the technique can be used for monitoring TBC health during thermal exposure. According to Han et al., 1997 Thermal imaging is also frequently used to monitor corrosion and disbonding in structural components.

Chapter 2 –Material Description and Methodology

2.0 Background Study

More advanced nuclear reactors are currently under investigation, are expected to allow more efficient and safer use of nuclear energy. In all these reactors, the fuel cladding is the most important safety barrier, as it restrains most of the radioactive fission products within its volume. The selection of fuel cladding material is based on many design constraints, such as neutron absorption cross section, service temperature, mechanical strength, toughness, neutron radiation resistance, thermal expansion, thermal conductivity, and chemical compatibility.

In this chapter, the main focuses are on deposition/coating technique implemented in this research. Silicon carbide powder was deposited on zirconium-alloy (Zr-1Nb) substrates to improve and enhance the previous mentioned properties of zirconium based coatings for cladding material design.

2.1 SLS Technique

SLS was invented by Carl R. Deckard and Joseph J. Beaman in the 1980s at the University of Texas [41]. The selective laser sintering (SLS) technique is a powder bed fusion technique in which a laser beam is used to fuse powder materials selectively according to the digital design of the built part [42].

Selective laser sintering (SLS) is an addictive manufacturing process in which three-dimensional printing is used to fabricate and design material by joining and solidifying under computer manipulation [43,44]. Selective laser sintering is highly applicable and durable manufacturing technique. It is capable of producing highly complex geometries. The method produces high-heat and chemically resistant applications. Despite the complexity of the SLS system, it is beneficial in managing time and cost of production. It is also possible to design and build large platforms for mega structural fabrications. In the course of the building of the print, automatic filling of the hollow spaces with the unused powder simultaneously takes place, hence making the SLS as shown in figure 2.1a deposition self-supporting and maintaining a huge degree of freedom in the design process [45].

The unique feature of laser processing of ceramics is that, at a specific time the interaction between ceramic powder and the laser beam only a tiny amount of laser energy is absorbed, some is transmitted and some is reflected. In order to evaluate the laser efficiency processing, it is necessary to quantified the intensity of the incident laser beam that coupled to the sample. This efficiency is described by the so-called absorption coefficient. There are also other quantities used to evaluate the laser processing are called reflectance and transmittance. These quantities are described by the following equations. The absorption coefficient [45], A, is given by:

$$A = 1 - T - R \tag{1.2.1}$$

A = (Absorption energy inside the sample)/ (Total incident energy)

while reflectance, R, is:

R = (Reflected energy from the sample)/ (Total incident energy)

and transmittance, T, is defined by:

T = (Transmitted energy through the sample)/ (Total incident energy)

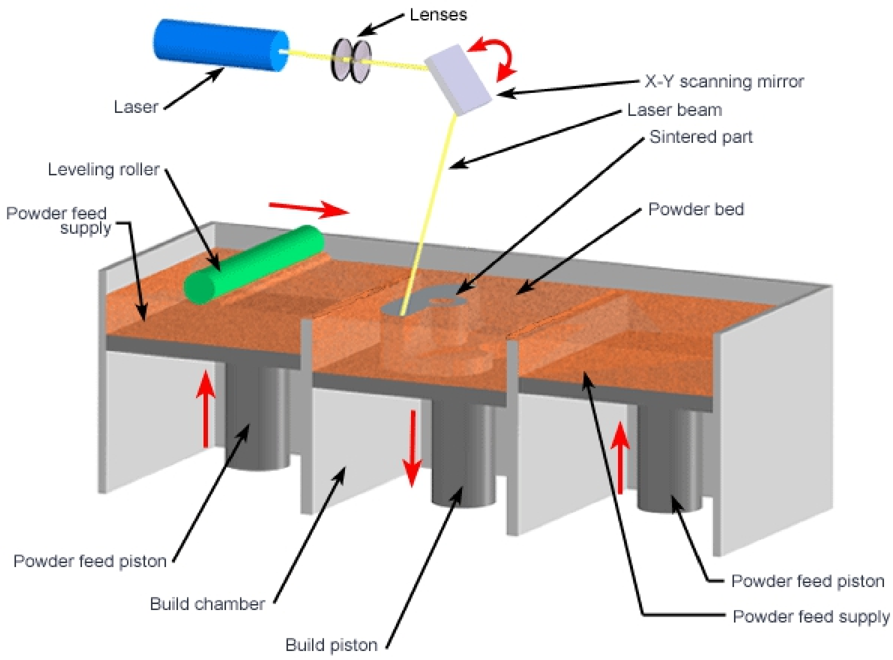

Figure 2.1.a – SLS machine

2.1.1 Material Description and Preparation

Two Zr-1%Nb substrates of fixed dimensions (60 mm × 30 mm × 2 mm) were used for the deposition. Before the deposition process, the two substrates surfaces were polished to an average roughness of 0.3 μm. With a working surface area of 1800 mm^2 (60 mm × 30 mm), each sample has been coated with a layer thickness 200 μm. The table 2.1a illustrates some main properties of the SiC type from the manufacturer.

Table 2.1a - Properties of SiC powder (trade name: SIKA DENSITEC L) [12]

Compositions						
SiC type	Al_2O_3	Y_2O_3	Binder	Moisture content		
Sintex 13C	5.5 %	3.5%	6 %	1 %		
Typical Physical Properties						
Average grain size	Bulk density	Hall Flow	Appearance	Density	Elastic Modulus	Fracture toughness, K_{IC}
100 µm	0.86 g/cm^3	22.5s / 50g at 20 ^oC	Light color	3.21 g/cm^3	24 GPa	4.5 MPa m$^{1/2}$

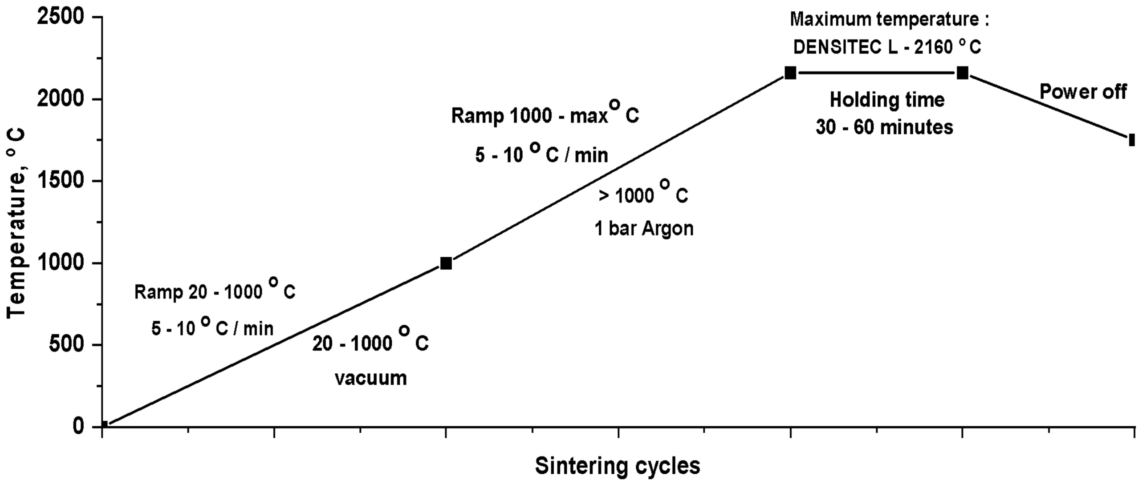

Figure 2.1.b – Scheme of a typical sintering cycles of the SiC powder used for coating [12].

The SLS system was equipped with an Ytterbium fiber laser (IPG Photonics, Moscow, Russia) of 1070 nm output wavelength and 500 W maximum power. A laser power of 125W was used depending on the variant in the course of manufacturing. A substrate is worked on at a time by carefully placing it in the chamber filled with air. In order to achieve sintering, the SiC powder is then sintered with heat generated from the laser by increasing the temperature of the local bed slightly below the melting point. The laser beam is directed in X and Y directions with galvanometer scanning system of very high frequencies at designated power as indicated in the table 2.1b. The laser then heats the SiC particles in specified directions until it is completely sintered through successive deposition. The lowering of the build platform whiles raising that of the delivery platform determined by the step size completes each layer thickness deposited. A layer thickness of 200 µm is established through repetitive deposition. A CAD 3D file in stereolithographic “ stl” format dictates the sintering path as programmed. The printed object from the powder bed is completely withdrawn from the chamber followed by a post processing technique of dusting off with compressed air. The Fig. 2.1c and table 2.1b gives a brief scheme on the SLS setup and the parameters followed in the fabrication process while Fig. 2.1d shows the schematic stages in the coating process.

Figure 2.1.c – Schematic view of the SLS setup

Table 2.2b - Parameters followed in the SLS fabrication

Samples	Laser power (W)	Scanning time (µs)	Laser speed (mm/s)	Coating thickness (µm)	SLS Filled Chamber
Sample 1	125	500	25	200	Air
Sample 2	125	500	25	200	Ar

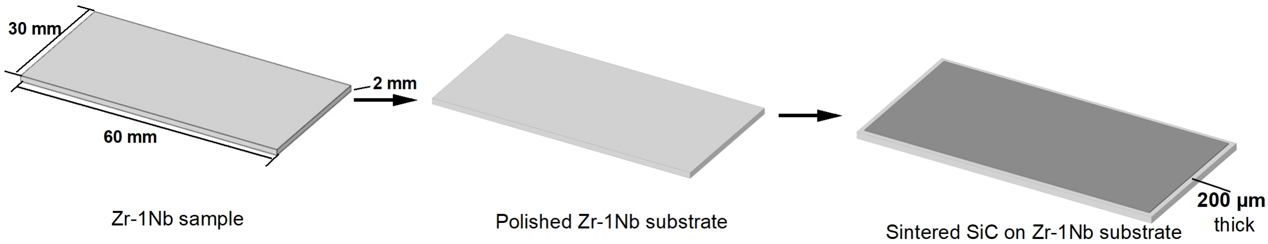

Figure 2.1. d – Schematic process undergone by samples in the coating of SiC on Zr-1Nb

2.2 Ultrasound Testing Investigation

Ceramic coatings may exhibit defects such as discontinuity in the deposition, miss-orientation of columnar structures, porosity, inclusions and infiltration by foreign materials. Whereas stringent quality control may eliminate the majority of these defects as-processed coatings. The others need to be identified by routine destructive and nondestructive testing (NDT) techniques. There are several NDT techniques with their intrinsic advantages and disadvantages.

The ultrasound testing method with C-scan image provides a valuable way to investigate the bulk of a material with sintered silicon carbide coatings [7]. Moreover, the ultrasound testing techniques possess some advantages over the rest in terms of accessibility, sensitivity to planar defects, cost and time effectiveness, higher productivity with no radiation risks. Hence, this paper is aimed to describe the performance of ultrasound testing technique on SiC coating**.**

The Fig. 2.2 represent the immersion ultrasound set-up. Samples are placed in the water tank and the probe adjusted at one edge of the sample.

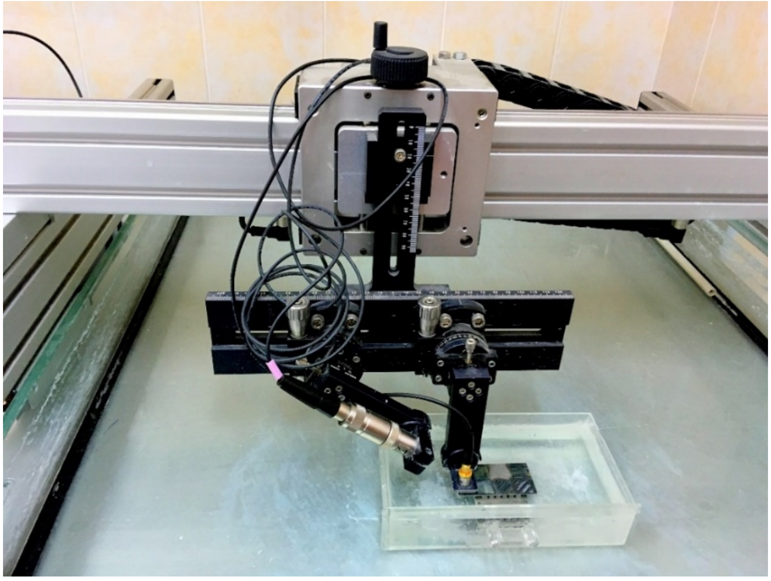

Figure 2.2.1 - Setup of immersion ultrasonic testing system

This is followed by calibrating the steps and dimensions to be covered during the scan from designed software on the computer. In the process of calibrating, the following parameters including frequency of 10 MHz and scan steps 0.1 microns. The sample is scanned automatically and the scan data collected and processed with MATLAB to obtain the Max-amplitude and Time of Flight (TOF).

2.3 Eddy Current Testing Investigation

2.3.1 Brief information from the theory.

Eddy current control methods are based on the excitation of eddy currents in electrically conducting objects by an alternating magnetic field and the dependence of the parameters of these currents on the properties of the object. The parameters of eddy currents thus, the amplitude, phase, and spatial distribution-depend on the geometric dimensions, shape, and structural features of the electrically conducting object, the electromagnetic characteristics of the material, the relative position of the object and the source of the exciting magnetic field, and the frequency and amplitude of the excitation current.

As a source of an alternating magnetic field, in most cases, a winding with an alternating electric current (field winding, field current) is used. Measurement information about the parameters of eddy currents can be obtained by measuring the characteristics of their magnetic field using an additional measuring winding (transformer measurement conversion), or using the same winding that is used to excite the magnetic field (parametric measurement conversion).

In the case of a transformer transformation (Fig. 2.3a), the output electrical signal reflecting the properties of an electrically conducting object is the complex electrical voltage of the measuring winding. In the case of parametric transformation (Fig. 2.3b), the electrical signal reflecting the properties of an electrically conducting object is the complex electrical resistance of the inductor winding. In the future, we will consider only the transformer version of the eddy current measuring converter (VTP) used in this work. A device consisting of one or more windings designed to excite eddy currents in an object of control and convert an electromagnetic field depending on the object's parameters into a converter.

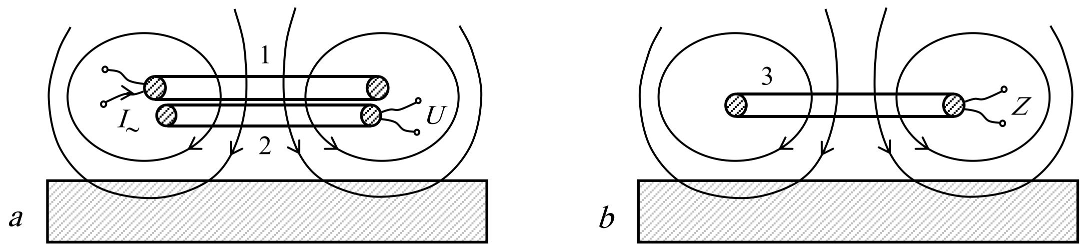

Figure 2.3.1.a - a Transformer (a) and parametric (b) eddy current measurement conversion options: 1-field winding; 2-measuring winding; 3-inductance winding

In this study, a frequency of 150 KHz was used through a two-coil transducer where one was involved in directing the eddy current signal through the sample and the output signal obtained through the other coil. Three major data including resistance, inductance and the phase shift angles the resistance and the inductance were obtained on the oscilloscope as shown in the Fig 2.3b. These data were save in a file and processed later by computing for the impedance in each point chosen on the sample.

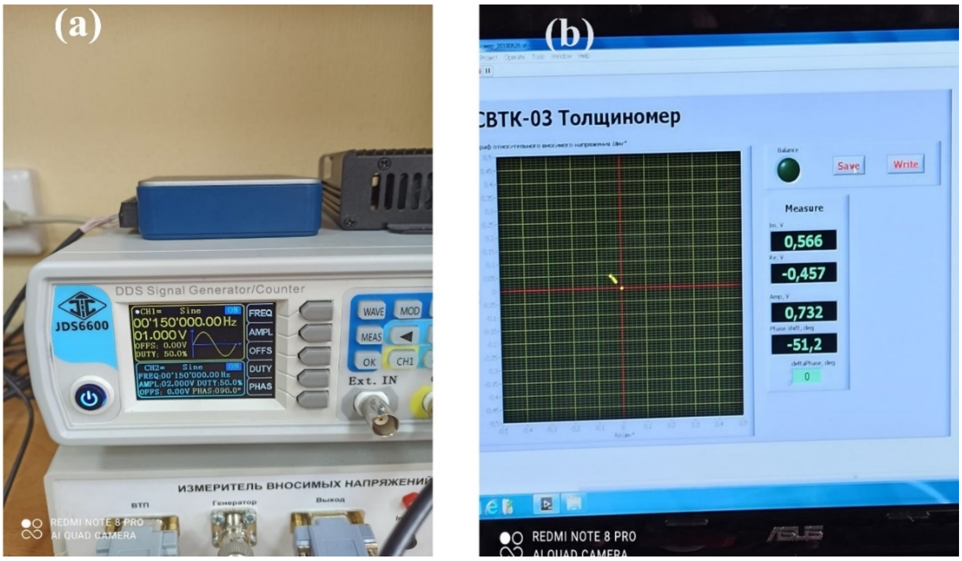

Figure 2.3.1.b – Set-up of the signal generator (a) and the output oscilloscope interface (b)

2.4 XRD Phase Composition

The experimental methods based on X-ray that are used in materials science and engineering can be divided into three main categories (**Spieß et al., 2009**). X-ray fluorescence spectroscopy is widely used for qualitative and quantitative chemical analysis, in particular, in electron microscopes. The X-ray radiography is an imaging technique based on the registration of the intensity passing through an object by using 19 films or detectors which allow making its internal structure visible due to the local variation of the absorption. One of the major developments of the last decades in this field is the X-ray computer tomography. Finally, the XRD methods are based on the ability of crystals to diffract X-rays in a characteristic manner allowing a precise study of the structure of crystalline phases. Recorded diffraction patterns contain additive contributions of several micro and macro-structural features of a sample. With the peak position, lattice parameters, space group, chemical composition, macros-tresses, or qualitative phase analysis can be investigated. Based on the peak intensity, information about crystal structure (atomic positions, temperature factor, or occupancy) as well as texture and quantitative phase analyses can be obtained. Finally, the peak shape gives information about sample broadening contributions (micro-strains and crystallite size) (Dinnebier and Billinge, 2008). (17- Epp, J. (2016). X-ray diffraction (XRD) techniques for materials characterization. In Materials characterization using nondestructive evaluation (NDE) methods (pp. 81- 124). Woodhead Publishing.)

2.4.1 XRD principle

When a crystal with an interplanar spacing d (crystal lattice constant) is irradiated by X-ray beam with a comparable wavelength λ, the X-ray diffraction, or the constructive interference between elastically scattered X-ray beams can be observed at specific angles 2θ when the Bragg's Law is satisfied.as shown in fig.14.

$$n\lambda = 2d \sin \theta$$

Where n is any integer. In most diffractometers the X-ray wavelength λ is fixed and the diffraction angle θ is measured by goniometer, therefore the crystal lattice constants can be decided by previous equation. Most of powder diffractometers use Bragg-Brentano Para focusing geometry, offering high-resolution and high beam intensity analysis at the cost of very precise alignment requirements and carefully prepared samples.

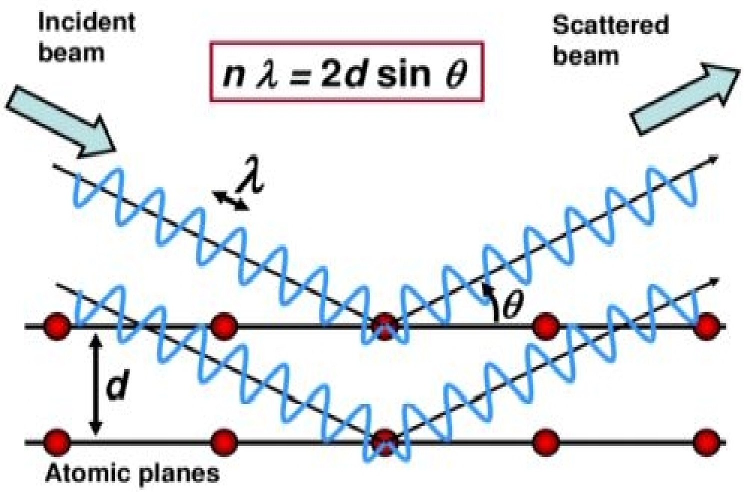

Figure 2.4.1.a – Schematic Diagram For XRD Principle

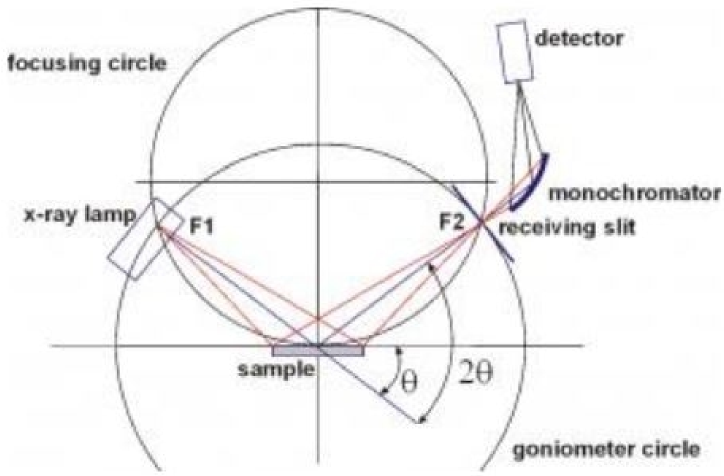

Figure 2.4.1.b – Bragg-Brentano (BB) Geometry

The incident angle ω between X-ray source and the sample is always 1/2 of the detector angle 2θ:1) ω:2θor θ:2θscan: with the X-ray tube fixed, the sample rotates at θ/min and the detector always at 2θ/min; and 2) θ: θ scan: the sample is fixed and the tube rotates at the same rate as the detector at θ/min. Sample surface is kept on the tangent plane of the focusing circle defined by three spots at sample, X-ray source and receiving slit. The incident- and diffracted beam slits move on a circle that is centered on the sample. Divergent X rays from the source hit the sample at different points on its surface. During the diffraction process the X rays are refocused at the detector slit. The PB optics provides accurate measurement of diffracted X-ray positions unaffected by sample shape. It is generally used to analyze powder sample profiles, the degree of preferred orientation and thin films.

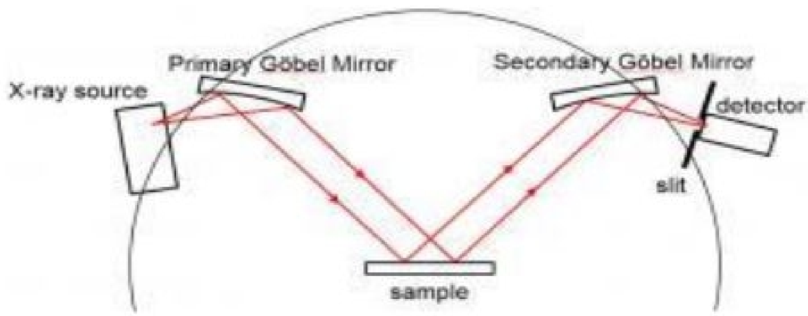

Figure 2.4.1.c – Parallel-Beam (PB) Geometry

A polycapillary collimating optic (Göbel Mirror) is used to form an intense parallel X-ray excitation beam resulting in very high X-ray intensities at the sample surface. No restrictions on XRD configuration from BB geometry which allows broader range of sample shapes and sizes [18,19].

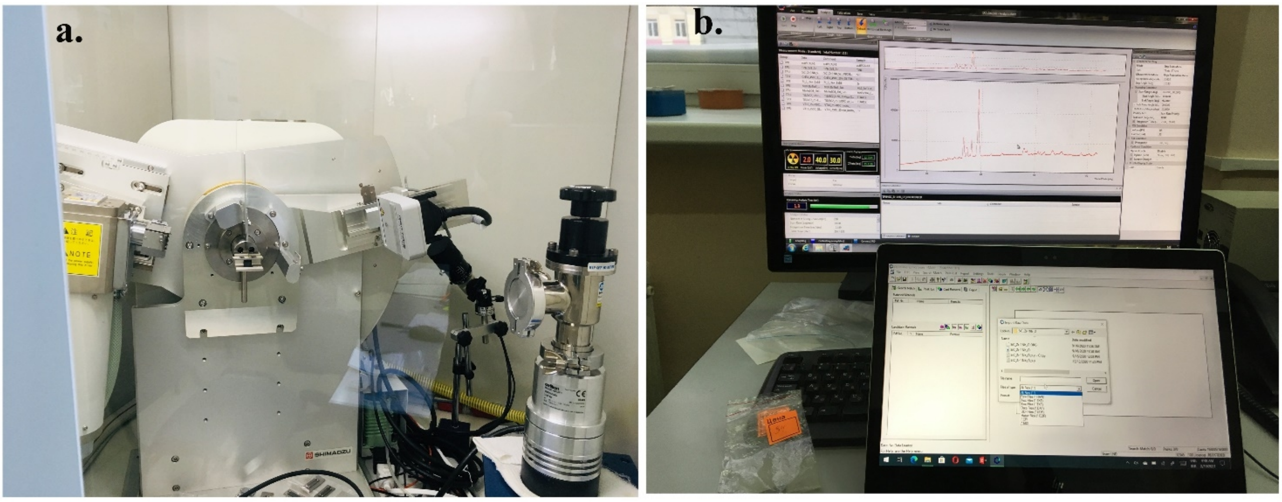

Figure 2.4.1.d - XRD 7000 diffractometer maxima (Shimadzu, Kyoto, Japan), (b) Search Match software in identifying the phases from the peak intensities of the raw data.

Chapter 3.0 – Results and Discussions

3.1 Results and Discussions on the Ultrasound technique

The obtained images associated with this study show the ultrasonic amplitude c-scan of the uncoated Zr-1Nb substrate (top and bottom sides) and the coated samples (top and reverse sides) which have been sintered in an air/argon environment using the SLS technique. The length and the width of the specimens are represented by X and Y axes respectively and the amplitude of the reflected ultrasonic signal is represented by Z axis. The Fig. 3.1b displays the Max – amplitude and Time of Flight (TOF) view of the samples top while 3.1c displays the reverse surfaces. The Fig. 3.1a gives a macro view of the original samples involved in the experiments.

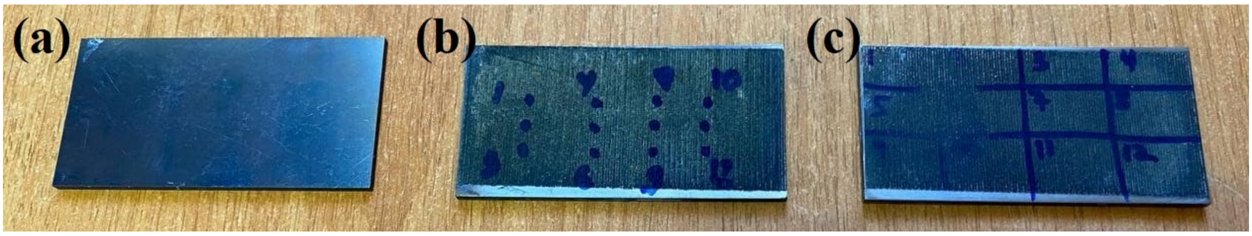

Figure 3.1.a – Macrograph of samples top surfaces: (a) uncoated Zr-1Nb, (b) SiC/Zr-1Nb in air atmosphere(b) and SiC/Zr-1Nb in Ar atmosphere(c)

The Max-amplitude three-dimensional view shows the state of the object's surface by first determining the starting point of the scan, and then depicting the scan area. It helps to see through the scanned images to locate defects and their depths. The amplitude does not give quantitative measurements on the thickness, however, it shows changes in surface conditions. For the images in (b) and (c), of the Fig. 3.1a shows the area with a maximum amplitude of about 3×10^4 which corresponds to uniform surface conditions as can be witnessed on the (a) which depicts polished Zr-1Nb alloy at the initial stage. The area with irregular surface conditions is characterized by lower values of amplitude and exhibiting non-uniformity corresponding to presence of defects on the surfaces. Maximum amplitude view shows how much the samples deviate from the normal due to discontinuity of the samples particle layers. According to the (a) in Fig. 3.1a, it shows a greater level of uniformity whiles the (b) and (c) shows a huge variation from the normal which in this case is the uncoated Zr-1Nb (a). SiC coating performed in an Ar atmosphere produces a greater variation form the normal compared to sample coated in air.

Time of flight information can help to establish the composition or the properties of a body. Therefore, TOF view in this study helps us to know the exact location and depths of defects in our samples. The time taken by the acoustic signal to travel through the samples and received by the transducer gives some details about the discontinuity encountered through the process. In Fig. 3.1b, the three views (d), (e) and (f) shows the time of flight 3D top views of the uncoated Zr-1Nb, SiC coated on Zr-1Nb in air and Ar atmosphere respectively. According to these three views, uncoated Zr-1Nb alloy depicted a higher level uniformity which still remains a reference to compare with the (e) and (f). The result of the Max amplitude and TOF both concludes a higher uniformity in the uncoated Zr-1Nb alloy followed by SiC coated Zr-1Nb in air while SiC coated Zr-1Nb presented a higher state of defects.

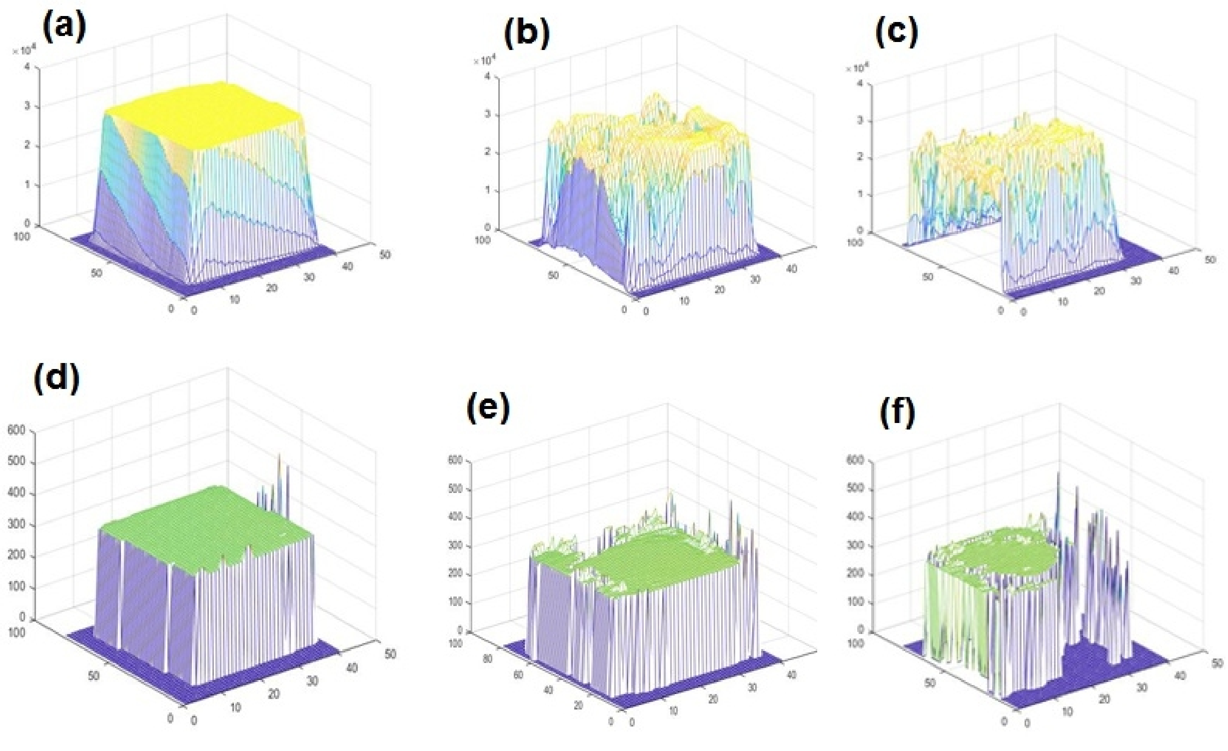

Figure 3.1.b – Max-amplitude view of Zr-1Nb (a), SiC coating on Zr-1Nb in air (b) and Ar. TOF view of Zr-1Nb (d), SiC coating on Zr-1Nb in air (e) and Ar (f) of samples top surfaces.

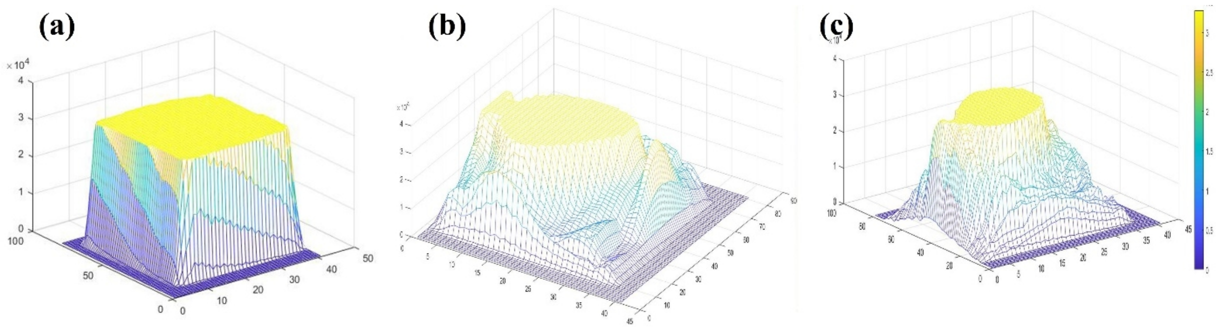

Figure 3.1.c – Max-amplitude view of Zr-1Nb (a), SiC coating on Zr-1Nb in air (b) and Ar. TOF view of Zr-1Nb (d), SiC coating on Zr-1Nb in air (e) and Ar (f) of samples reverse / bottom surfaces.

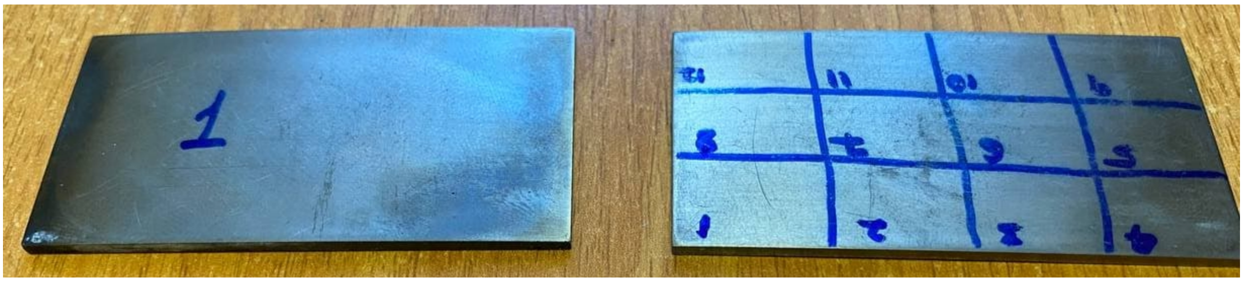

Figure 3.1.d – Macrograph of the heat affected reverse portion of the coated samples

The Fig. 3.1c shows the max-amplitude scanned results of the reverse side of the uncoated Zr-1Nb substrate (a), reverse view of SiC coated Zr-1Nb in air (b) and reverse view of SiC coated Zr-1Nb in Ar. The main samples under discussion in the Fig 3.1c has to do mainly with the bottom view of the coated samples. It is clear that, most of the individual amplitudes converge at the center depicting stronger amplitude around the central part while weaker amplitude signal visible around the entire edges of the sample. These outcomes might be due to the thermal damage encountered during the laser sintering process. However, this information will help to direct future works in controlling the thermal behaviors during the fabrication stage.

3.2 Results and Discussion on Eddy Current Testing

After calculating the impedance from the obtained results discussed in chapter 2.3, Matlab and XYZ mesh programmes were engaged in obtaining the three dimensional view of the samples which are shown in the Fig. 3.2. According to observations from Fig.3.2, the maximum impedance is about 5.8×10^{-3} for uncoated

Zr-1Nb which serves as the reference frame. SiC coated Zr-1Nb in air and Ar atmosphere resulted to approximately 6.0×10^{-3} and 6.5×10^{-3} correspondingly. The impedance varies from the reference object's value due to the sintering of extra layers of SiC particles which also present a totally difference composition from the Zr-alloy. Also, these impedance values authenticate the results by proving SiC being a semiconductor possessing slightly higher impedance than metallic Zr-alloy. Moreover, SiC coated in air ones again demonstrated higher uniformity to that of SiC coated in Ar atmosphere as seen in ultrasound testing results. These results of coating in air presented better uniformity as well as less defects in both ultrasound and eddy current testing. Therefore, these outstanding results needed to be investigate with computed tomography and SEM techniques in order to establish a solid fact that coating air atmosphere yielded good uniformity than coating performed in an inert environment. to which these samples needs to be investigated.

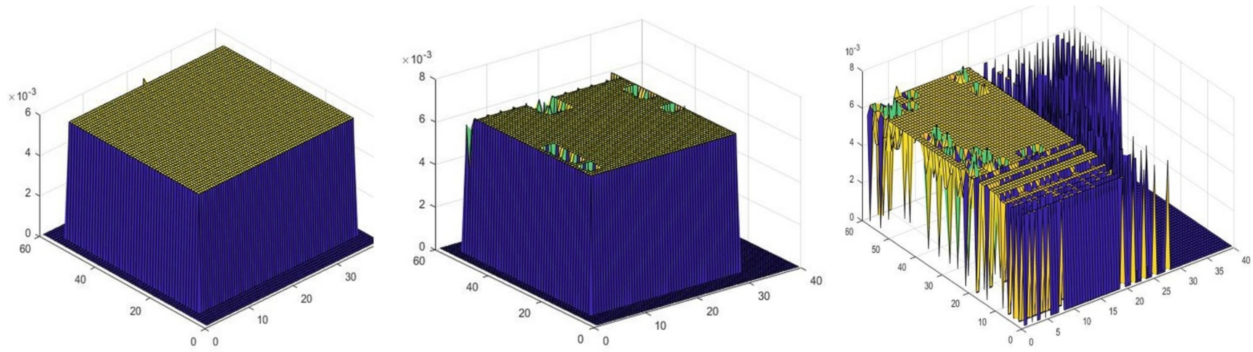

Figure 3.2.1 – XYZ mesh view of the impedance through the samples, uncoated Zr-1Nb (left), SiC coated Zr-1Nb in air atmosphere (middle), and in Ar atmosphere (right)

3.3 Results and Discussion on Phase Composition

3.3.1 Qualitative analysis on the XRD phase compositions

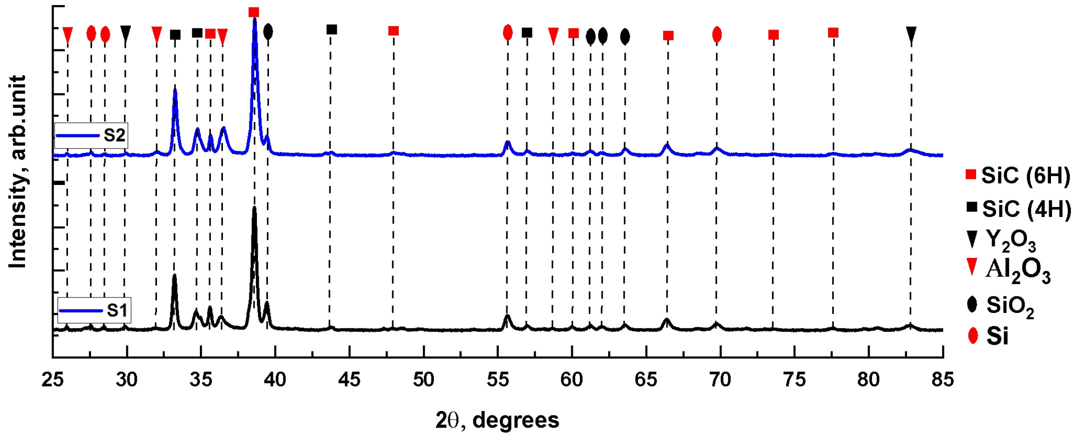

Figure 3.3.1.1 - XRD phase composition of samples, SiC/Zr-1Nb coated in air atmosphere (S1) and SiC/Zr-1Nb coated in Ar atmosphere (S2)

The Fig. 3.3 reveals the main phase compositions observed on the samples surfaces to sub-surfaces. From the Fig. 3.3, it is observed that the four main phases including SiC(6H), SiC(4H), Y2O3 and Al2O3 were seen in all samples which forms the main phases of the SiC powder from the manufacturer as stated in the table 2. After Selective Laser Sintering of SiC powder on the Zr-1Nb alloy, oxides phases including SiO2 and YAlO3 were formed as shown on the Fig. 3.3.

3.3.2 Quantitative analysis on the XRD phase compositions

The table 3.3a, 3,3b and 3.3c contained the phase transformation from the powder state to sintering in air and Ar atmosphere. As stipulated in the table, essential oxides such as Y2O3, Al2O3 were still visible on the surfaces after coating. However, an essential oxide, SiO2 cubic crystal structure was also formed after the sintering process while including single Si-cubic phases. These phase compositions differ from sintering in air and Ar atmosphere and could play a role in the variations encountered during non-destructive investigations.

Table 3.1a – Phase composition of the SiC powder used

Sample	Phases	Phase content, vol.%
SiC (6H)	Hexagonal	64
SiC (4H)	Hexagonal	28.1
Y2O3	Cubic	1.7
Al2O3	Rhombohedral	6.2

Table 3. 2b – Phase composition of sample after sintering in air atmosphere

Sample	Phases	Phase content, vol.%
SiC(6H)	Hexagonal	54.2
SiC(4H)	Hexagonal	20.7
Y2O3	Cubic	6.3
Al2O3	Rhombohedral	6.3
SiO2	Cubic	6.3
Si	Cubic	6.3

Table 3.3c - Phase composition of sample after sintering in Ar atmosphere

Sample	Phases	Phase content, vol.%
SiC(6H)	Hexagonal	56.2
SiC(4H)	Hexagonal	18.4
Y2O3	Cubic	6.2
Al2O3	Rhombohedral	7.1
SiO2	Cubic	7.3
Si	Cubic	4.8

Conclusion

SiC micro-composites were deposited on Zr-1Nb alloy substrates in air and Ar atmosphere using selective laser sintering and investigated under Non-destructive techniques including immersion ultrasound testing, eddy current testing and XRD phase composition. The outcomes of the maximum amplitude and TOF 3D views of the ultrasound immersion technique both concludes a higher uniformity in the uncoated Zr-1Nb alloy followed by SiC coated Zr-1Nb in air before SiC coated Zr-1Nb in Ar atmosphere. According to eddy current testing results, SiC coated Zr-1Nb in air and Ar atmosphere resulted to impedance of approximately 6.0×10^{-3} and 6.5×10^{-3} correspondingly while coating done in air ones again shown good uniformity as evidenced in the ultrasound results. Both ultrasound testing and eddy current results proves SiC coating in air atmosphere having a better uniformity compared to coating done in Ar atmosphere. XRD phase qualitative and quantitative analysis reveals the formation and distribution protective oxides such SiO2, Al2O3, Y2O3 which could protect the underlying layer from atmospheric contaminants. These two NDT approaches shows that both are capable of visualizing the surface profile of the specimens as well as various reactor components. Ultrasonic immersion technique and eddy current testing have the potential to be used for in-service inspection of SiC coatings on Zr alloy tubes to ensure the structural integrity in this particular design of cladding tubes in the nuclear power industry. Due to the surface conditions of SiC coating, surface finishing is required to provide a smooth coating surface in order not to mask indications from the surface defects. Further work will be done to develop a methodology to detect the sub-surface defects, in particular the boundary layer between the SiC and the substrate which is important to determine the integrity of the sintering process.

Chapter 4 - Financial management, resource efficiency and resource saving

The purpose of this section discusses the issues of competitiveness, resource efficiency and resource saving, as well as financial costs regarding the object of study of master's thesis. Competitiveness analysis is carried out for this purpose. SWOT analysis helps to identify strengths, weaknesses, opportunities and threats associated with the project, and give an idea of working with them in each particular case. For the development of the project requires funds that go to the salaries of project participants and the necessary equipment, a complete list is given in the relevant section. The calculation of the resource efficiency indicator helps to make a final assessment of the technical decision on individual criteria and in general.

The coated Zircalloy substrate (Zr.1Nb) by Silicon Carbide laser technique is one the advanced solution for treatment surface whose very thin thickness has benefits for safety, protection and low cost from economical point of view. Beside to thermal and mechanical properties of SiC which make it on the priority list in Russian trade market.

Competitiveness analysis of technical solutions

In order to find sources of financing for the project, it is necessary, first, to determine the commercial value of the work. Analysis of competitive technical solutions in terms of resource efficiency and resource saving allows to evaluate the comparative effectiveness of scientific development. This analysis is advisable to carry out using an evaluation card.

First of all, it is necessary to analyze possible technical solutions and choose the best one based on the considered technical and economic criteria.

Evaluation map analysis presented in Table 1. The position of your research and competitors is evaluated for each indicator by you on a five-point scale, where 1 is the weakest position and 5 is the strongest. The weights of indicators determined by you in the amount should be 1. Analysis of competitive technical solutions is determined by the formula:

$$C = \sum W_i \cdot P_i, \tag{4.1}$$

C - the competitiveness of research or a competitor;

Wi– criterion weight;

Pi – point of i-th criteria.

Table 4.1. Evaluation card for comparison of competitive technical solutions

Evaluation criteria example	**Criterion weight**	**Points**			**Competitiveness** Taking into account weight coefficients		
		P_f	P_{i1}	P_{i2}	C_f	C_{i1}	C_{i2}
1	2	3	4	5	6	7	8
Technical criteria for evaluating resource efficiency							
1. Energy efficiency	0.1	5	4	3	0.5	0.4	0.4
2. Reliability	0.2	5	3	5	1	0.6	0.8
3. Safety	0.2	5	3	4	1	0.6	0.6
4. Functional capacity	0.1	5	5	4	0.5	0.5	0.4
Economic criteria for performance evaluation							
1. Development cost	0.15	4	3	4	0.6	0.2	0.6
2. Market penetration rate	0.1	4	2	3	0.4	0.6	0.3
3. Expected lifecycle	0.15	5	5	4	0.75	0.25	0.6
Total	**1**	**33**	**25**	**26**	**4.75**	**3.5**	**3.7**

The enhancement of zircalloy surface and compared it with the traditional one without coating is one of selective way to know the advantages and disadvantages for each alloy and used it in the industrial trend for international companies such as Rosatom. In the previous table shows that this comparison between the old alloy and new smart alloy which we had already received (Zr.1Nb). as a consequence, it is promising alloy in due to high safety, energy efficiency, long lifetime, and low capital cost.

SWOT analysis

Complex analysis solution with the greatest competitiveness is carried out with the method of the SWOT analysis: Strengths, Weaknesses, Opportunities and Threats. The analysis has several stages. The first stage consists of describing the strengths and weaknesses of the project, identifying opportunities and threats to the project that have emerged or may appear in its external environment. The second stage consists of identifying the compatibility of the strengths and weaknesses of the project with the external environmental conditions. This compatibility or incompatibility should help to identify what strategic changes are needed.

Table 4.2 - SWOT analysis

	Strengths: S1. High conductivity, low thickness, and high hardness and ductility S2. Slow rate of hydrogen generation from reaction with water at high temperatures S3. Anti-corrosion and lower needs for enrichment	**Weaknesses:** W1. Oxidation process lead to minimize the lifetime W2. Lack information about new coating technique W3. Industrial defect for synthesis ways
Opportunities: O1. Saving thermal energy O2. Decreasing capital cost O3. Increasing efficiency of heat transfer	It is now one of the solutions to many of the problems that affect nuclear manufacture and development. It improves NPP's power and efficiency. It enables a wide range of	It causes manufacturing procedures to be delayed as a result of the increased information about it. It results in production problems. As a result, marketing

	products to be manufactured at a minimal cost.	penetration takes a long time.
Threats: T1. Natural catastrophes T2. Calculations mistakes during implementation T3. Changing its properties during operation due to neutrons radiation	It leads to more stringent safety and protection standards. It encourages mass production of high-quality and quantity goods. It causes the lifespan and expiration dates to be extended.	It leads to its use in high-limit applications that are not subject to natural catastrophes. As a result, it is manufactured under strict supervision from authorised users.

Project Initiation

The initiation process group consists of processes that are performed to define a new project or a new phase of an existing one. In the initiation processes, the initial purpose and content are determined, and the initial financial resources are fixed. The internal and external stakeholders of the project who will interact and influence the overall result of the research project are determined.

Table 4. 3 – Stakeholders of the project

Project stakeholders	Stakeholder expectations
Nuclear industry organizations	Enhancing the cladding's lifetime and assuring great thermal and mechanical performance. Competitiveness in the market compared to old zirconium alloy without coating.

Table 4.4 – Purpose and results of the project

Purpose of project:	Using coating technique to develop and enhance the surface of Zircalloy and test it by non-destructive ways using them as a cladding in reactor core.
Expected results of the project:	High thermal and mechanical efficiency, increasing the expiring dates of reactor cladding as a result high safety and low cost.
Criteria for acceptance of the project result:	The project meets all of the needed standards and qualities, including high reliability, safety, and longevity. It also saves a significant amount of electricity.
Requirements for the project result:	It is necessary to devote sufficient time to the manufacturing methods in order to assure the expansion of scientific knowledge by conducting research and performing exact calculations.
	It must prevent manufacturing flaws and meet all safety and quality requirements.
	To avoid poor storage, it must work in highly marketing distribution by making widespread announcements.

The organizational structure of the project

It is necessary to solve some questions: who part of the working group of this project will be, determine the role of each participant in this project, and prescribe the functions of the participants and their number of labor hours in the project.

Table 4.5 – Structure of the project

№	Participant	Role in the project	Functions	Labor time, hours (working days (from table 7) × 6 hours)
1	Professor. Andrey M. Lider	Head of project	Creating the plan of work, managing the research process Verifying of work evolution through weekly meetings.	132h
2	Engineer	Executor	Conducting experiments, evaluating data, making graphs, analysis of the results.	546h

Project limitations

Project limitations are all factors that can be as a restriction on the degree of freedom of the project team members.

Table 4.6 – Project limitations

Factors	Limitations / Assumptions
3.1. Project's budget	**296434.4**
3.1.1. Source of financing	Internal TPU
3.2. Project timeline:	01.02.2021-28.05.2021
3.2.1. Date of approval of plan of project	17.02.2021
3.2.2. Completion date	21.05.2021

Project Schedule

As part of planning a science project, you need to build a project timeline and a Gantt Chart.

Table 4.7 – Project Schedule

Job title	Duration, working days	Start date	Date of completion	Participants
Layout and objectives of project plan	3	01.02.2021	03.02.2021	S
Special literature selection and studying	9	04.02.2021	13.02.2021	S, E
Timetable Development	2	15.02.2021	16.02.2021	S, E
literature discussion	2	17.02.2021	18.02.2021	S, E
Conducting experiments	22	19.02.2021	18.03.2021	E

Calculation of standard parameters	30	19.03.2021	22.04.2021	E
Analysis the data and discussion	20	23.04.2021	20.05.2021	E
Summarizing	6	21.05.2021	27.05.2021	S, E
Total sum:	94			

A Gantt chart, or harmonogram, is a type of bar chart that illustrates a project schedule. This chart lists the tasks to be performed on the vertical axis, and time intervals on the horizontal axis. The width of the horizontal bars in the graph shows the duration of each activity.

Table 4. 8 – A Gantt charts

№	Activities	Participants	T_c, days	Duration of the project											
				February			March			April			May		
				1	2	3	1	2	3	1	2	3	1	2	3
1	Layout and objectives of project plan	S	3												
2	Special literature selection and studying	S, E	9												
3	Timetable development	S, E	2												
4	Literature discussion	S, E	2												
5	Conducting experiments	E	22												
6	Calculation of standard parameters	E	30												
7	Analysis the data and discussion	E	20												
8	Summarizing	S, E	6												

Supervisor (S) – ; Engineer (E) –

Scientific and technical research budget

The amount of costs associated with the implementation of this work is the basis for the formation of the project budget. This budget will be presented as the lower limit of project costs when forming a contract with the customer.

To form the final cost value, all calculated costs for individual items related to the manager and the student are summed.

In the process of budgeting, the following grouping of costs by items is used:

Material costs of scientific and technical research;

- costs of special equipment for scientific work (Depreciation of equipment used for design);
- basic salary;
- additional salary;
- labor tax;
- overhead.

Calculation of material costs

The calculation of material costs is carried out according to the formula:

$$C_m = (1 + k_T) \cdot \sum_{i=1}^{m} P_i \cdot N_{consi} \quad (4.2)$$

Where: m – the number of types of material resources consumed in the performance of scientific research;

N_{consi} – the amount of material resources of the i-th species planned to be used when performing scientific research (units, kg, m, m^2, etc.);

P_i – the acquisition price of a unit of the i-th type of material resources consumed (rub. /units, rub. /kg, rub. /m, rub. /m^2, etc.);

k_T – coefficient taking into account transportation costs.

Prices for material resources can be set according to data posted on relevant websites on the Internet by manufacturers (or supplier organizations).

Table 4.9 – Material costs

Name	Unit	Amount	Price per unit, rub.	Material costs, rub.
A4 printer paper	pcs	1	300	300
Printer cartridge	pcs	1	2500	2500
Ballpoint pen	pcs	2	50	100
Pencil	pcs	1	100	100
Pencil grills	pcs	1	50	50
Drawing paper	pcs	7	20	140
Total				3190

Costs of special equipment

This point includes the costs associated with the acquirement of special equipment (instruments, stands, devices and mechanisms) necessary to carry out work on a specific topic.

Table 4.10a. – Costs of special equipment (+software)

№	Equipment identification	Quantity of equipment	Price per unit, rub.	Total cost of equipment, rub.
1.	Laptop	1	50000	50000
2.	Laser sintering device	1	500000	500000
3.	Ultrasound device	1	655000	655000
4.	Eddy current device	1	50000	50000
5.	XRD device	1	874000	874000

OR

Calculation of the depreciation. Depreciation is not charged if an equipment cost is less than 40 thousand rubles, its cost is taken into account in full.

If you use available equipment, then you need to calculate depreciation:

$$A = \frac{C_{перв} * H_a}{100} \qquad (4.3)$$

A - annual amount of depreciation;

$C_{перв}$ - initial cost of the equipment;

$H_a = \frac{100}{T_{сл}}$ - rate of depreciation;

$T_{сл}$ - life expectancy.

Table 4.10b – Depreciation of special equipment (+software)

№	equipment identification	Quantity of equipment	Total cost of equipment, rub.	Life expectancy, year	Working days	Depreciation for the duration of the project, rub.
1.	Laptop	1	50000	5	94	2575.3
2.	Laser sintering device	1	500000	10	22	3013.7
3.	Ultrasound device	1	655000	10	22	3948
4.	Eddy current device	1	50000	5	22	602.7
5.	XRD device	1	874000	10	22	5268
Total						15408

Basic salary

This point includes the basic salary of participants directly involved in the implementation of work on this research. The value of salary costs is determined based on the labor intensity of the work performed and the current salary system

The basic salary (S_b) is calculated according to the formula:

$$S_b = S_a \cdot T_w \tag{4.4}$$

Where: S_b – basic salary per participant;

T_w – the duration of the work performed by the scientific and technical worker, working days;

S_d - the average daily salary of a participant, rub.

The average daily salary is calculated by the formula:

$$S_d = \frac{S_m \cdot M}{F_v} \tag{4.5}$$

Where: S_m – monthly salary of a participant, rub;

M – the number of months of work without leave during the year:

at holiday in 48 days, M = 11.2 months, 6 day per week;

F_v – valid annual fund of working time of scientific and technical personnel (251 days).

Table 4.11 - The valid annual fund of working time

Working time indicators	
Calendar number of days	365
The number of non-working days - weekend - holidays	 52 14
Loss of working time - vacation - isolation period - sick absence	 48

The valid annual fund of working time	251

Monthly salary is calculated by formula:

$$S_{month} = S_{base} \cdot (k_{premium} + k_{bonus}) \cdot k_{reg} \qquad (4.6)$$

Where: S_{base} – base salary, rubles;

$k_{premium}$ – premium rate;

k_{bonus} – bonus rate;

k_{reg} – regional rate.

Table 4.12 – Calculation of the base salaries

Performers	S_{base}, rubles	$k_{premium}$	k_{bonus}	k_{reg}	S_{month}, rub.	W_d, rub.	T_p, workdays (from table 7)	W_{base}, rub.
Supervisor	36174	-	-	1,3	47026.2	2098.4	22	46165.9
Engineer	18426				23953.8	1068.9	91	97265.8
Total					143432			

Labor tax

Tax to extra-budgetary funds are compulsory according to the norms established by the legislation of the Russian Federation to the state social insurance (SIF), pension fund (PF) and medical insurance (FCMIF) from the costs of workers.

Payment to extra-budgetary funds is determined of the formula:

$$P_{social} = k_b \cdot (W_{base} + W_{add}) \qquad (4.7)$$

Where: k_b – coefficient of deductions for labor tax.

In accordance with the Federal law of July 24, 2009 No. 212-FL, the amount of insurance contributions is set at 30%. Institutions conducting educational and scientific activities have rate - 27.1%.

Table 4.13 - Labor tax

	Project leader	Engineer
Coefficient of deductions	0.271	
Salary (basic and additional), rubles	46164.4	97265.8
Labor tax, rubles	12510.5	26359
Total	38869.5	

Overhead costs

Overhead costs include other management and maintenance costs that can be allocated directly to the project. In addition, this includes expenses for the maintenance, operation and repair of equipment, production tools and equipment, buildings, structures, etc.

Overhead costs account from 30% to 90% of the amount of base and additional salary of employees.

Overhead is calculated according to the formula:

$$C_{ov} = k_{ov} \cdot (W_{base} + W_{add}) \quad (4.8)$$

Where: k_{ov} – overhead rate.

Table 4.14 - Overhead

	Project leader	Engineer
Overhead rate	0.7	
Salary, rubles	46164.4	97265.8
Overhead, rubles	32315.1	68086.1
Total	100401.2	

Other direct costs

Energy costs for equipment are calculated by the formula:

$$C = P_{el} \cdot P \cdot F_{eq}$$

Where: P_{el} − power rates (5.8 rubles per 1 kWh);

P − power of equipment, kW;

F_{eq} − equipment usage time, hours.

Laptop

$$C = P_{el} \cdot P \cdot F_{eq} = 5.8 \cdot 0.08 \cdot 564 \approx 262 \text{ rub.}$$

Laser sintering device

$$C = P_{el} \cdot P \cdot F_{eq} = 5.8 \cdot 0.1 \cdot 132 \approx 76.56 \text{ rub.}$$

Ultrasound device

$$C = P_{el} \cdot P \cdot F_{eq} = 5.8 \cdot 0.15 \cdot 132 \approx 114.84 \text{ rub.}$$

Eddy current device

$$C = P_{el} \cdot P \cdot F_{eq} = 5.8 \cdot 0.19 \cdot 132 \approx 145.5 \text{ rub.}$$

XRD device

$$C = P_{el} \cdot P \cdot F_{eq} = 5.8 \cdot 0.2 \cdot 132 \approx 153 \text{ rub.}$$

Total power consumption for equipment =

262 + 76.56 + 114.84 + 145.5 +153 = 752 rub

Formation of budget costs

The calculated cost of research is the basis for budgeting project costs.

Determining the budget for the scientific research is given in the table 15.

Table 4.15 - Items expenses grouping

Name	**Cost, rubles**
Material costs	3190
Equipment costs	15408
Basic salary	137813.7
Additional salary	0
Labor tax	38869.5
Overhead	100401.2
Other direct costs	752
Total planned costs	**296434.4**

5. Evaluation of the comparative effectiveness of the project

Determination of efficiency is based on the calculation of the integral indicator of the effectiveness of scientific research. Its finding is associated with the definition of two weighted average values: financial efficiency and resource efficiency.

The integral indicator of the financial efficiency of a scientific study is obtained in the course of estimating the budget for the costs of three (or more) variants of the execution of a scientific study. For this, the largest integral indicator of the implementation of the technical problem is taken as the calculation base (as the denominator), with which the financial values for all the options are correlated.

The integral financial measure of development is defined as:

$$I_f^d = \frac{C_i}{C_{\max}} \tag{4.9}$$

Where: I_f^d – integral financial measure of development;

C_i – the cost of the i-th version;

C_{max} – the maximum cost of execution of a research project (including analogues).

The obtained value of the integral financial measure of development reflects the corresponding numerical increase in the budget of development costs in times (the value is greater than one), or the corresponding numerical reduction in the cost of development in times (the value is less than one, but greater than zero).

Since the development has one performance, then $I_f^d = 1$.

The integral indicator of the resource efficiency of the variants of the research object can be determined as follows:

$$I_T^a = \sum_{i=1}^{n} a_i b_i^a \qquad I_T^p = \sum_{i=1}^{n} a_i b_i^p$$

Where: I_m – integral indicator of resource efficiency for the i-th version of the development;

a_i – the weighting factor of the i-th version of the development;

b_i^a, b_i^p – score rating of the i-th version of the development, is established by an expert on the selected rating scale;

n – number of comparison parameters.

The calculation of the integral indicator of resource efficiency is presented in the form of table 17.

Table 4.16 – Evaluation of the performance of the project

Criteria	**Weight criterion**	**Points**	
		Zr-alloy with coating	**Zr-alloy without**

			coating
1. Energy efficiency	0.1	5	4
2. Reliability	0.2	5	4
3. Safety	0.1	5	3
4. Functional capacity	0.3	5	4
Economic criteria for performance evaluation			
1. The cost of development	0.15	4	4
2. Market penetration rate	0.1	4	3
3. Expected life	0.15	5	4
Total	1	32	26

The integral indicator of the development efficiency (I_e^p) is determined on the basis of the integral indicator of resource efficiency and the integral financial indicator using the formula:

$$I_e^p = \frac{I_m^p}{I_f^d};\ I_e^a = \frac{I_m^a}{I_f^a}. \quad (4.10)$$

Comparison of the integral indicator of the current project efficiency and analogues will determine the comparative efficiency. Comparative effectiveness of the project:

$$E_c = \frac{I_e^p}{I_e^a} = \frac{4.75}{4.1} \approx 1.28. \quad (4.11)$$

Thus, the effectiveness of the development is presented in table 18.

Table 4.17 – Efficiency of development

№	Indicators	Points	
		Zr-alloy with coating	**Zr-alloy without coating**
1	Integral financial measure of development	1	1
2	Integral indicator of resource efficiency of development	4.75	3.7
3	Integral indicator of the development efficiency	4.75	3.7

Comparison of the values of integral performance indicators allows us to understand and choose a more effective solution to the technical problem from the standpoint of financial and resource efficiency.

Conclusion

Thus, in this section was developed stages for design and create competitive development that meet the requirements in the field of resource efficiency and resource saving.

These stages include:

– development of a common economic project idea, formation of a project concept;
– organization of work on a research project;
– identification of possible research alternatives;
– research planning;
– assessing the commercial potential and prospects of scientific research from the standpoint of resource efficiency and resource saving;
– determination of resource (resource saving), financial, budget, social and economic efficiency of the project.

As a result, the current project is more competitive from the point of reliability and safety. The competitiveness of project is higher than competitor's option. The budget of the project equals **296434.4** rubles and integrating efficiency indicator is 1.28 times greater in comparison with the competitor, and it has a value 4.75.

Chapter 5.0 Social responsibility

1.1 Introduction

SiC is considered to provide outstanding passive safety features in beyond-design-basis severe accident scenarios. SiC is anticipated to provide additional benefits over Zr alloys: smaller neutron absorption cross-sections, general chemical inertness, ability to withstand higher fuel burn-ups and higher temperatures, exceptional inherent radiation resistance, lack of progressive irradiation growth, and low induced activation/low decay heat. Moreover, SiC is considered to be permanently stable in nuclear waste.

Fuels and core structures in current light water reactors (LWRs) are vulnerable to catastrophic consequences in the event of loss of coolant or active cooling, as was evidenced by the March 2011 Fukushima Daichi Nuclear Power Plant accident. This vulnerability is attributed primarily to the rapid oxidation kinetics of zirconium (Zr) alloys in a water vapor environment at very high temperatures, which results in the production of explosive hydrogen.

1.2 Legal and organizational items in providing safety

Nowadays one of the main ways to radical improvement of all prophylactic work referred to reduce Total Incidents Rate and occupational morbidity is the widespread implementation of an integrated Occupational Safety and Health management system. That means combining isolated activities into a single system of targeted actions at all levels and stages of the production process.

Occupational safety is a system of legislative, socio-economic, organizational, technological, hygienic and therapeutic and prophylactic measures and tools that ensure the safety, preservation of health and human performance in the work process.

According to the Labor Code of the Russian Federation, every employee has the right:

- to have a workplace that meets Occupational safety requirements.
- to have a compulsory social insurance against accidents at manufacturing and occupational diseases;
- to receive reliable information from the employer, relevant government bodies and public organizations on conditions and Occupational safety at the workplace, about the existing risk of damage to health, as well as measures to protect against harmful and (or) hazardous factors;
- to refuse carrying out work in case of danger to his life and health due to violation of Occupational safety requirements;
- be provided with personal and collective protective equipment in compliance with Occupational safety requirements at the expense of the employer;
- for training in safe work methods and techniques at the expense of the employer;
- for personal participation or participation through their representatives in consideration of issues related to ensuring safe working conditions in his workplace, and in the investigation of the accident with him at work or occupational disease;
- for extraordinary medical examination in accordance with medical recommendations with preservation of his place of work (position) and secondary earnings during the passage of the specified medical examination;
- for warranties and compensation established in accordance with this Code, collective agreement, agreement, local regulatory an act, an employment contract, if he is engaged in work with harmful and (or) hazardous working conditions.

The labor code of the Russian Federation states that normal working hours may not exceed 40 hours per week, the employer must keep track of the time worked by each employee.

Rules for labor protection and safety measures are introduced in order to prevent accidents, ensure safe working conditions for workers and are mandatory for workers, managers, engineers and technicians.

1.3 Basic ergonomic requirements for the correct location and arrangement of researcher's workplace

The workplace when working with a PC should be at least 6 square meters. The legroom should correspond to the following parameters: the legroom height is at least 600 mm, the seat distance to the lower edge of the working surface is at least 150 mm, and the seat height is 420 mm. It is worth noting that the height of the table should depend on the growth of the operator.

The following requirements are also provided for the organization of the workplace of the PC user: The design of the working chair should ensure the maintenance of a rational working posture while working on the PC and allow the posture to be changed in order to reduce the static tension of the neck and shoulder muscles and back to prevent the development of fatigue.

The type of working chair should be selected taking into account the growth of the user, the nature and duration of work with the PC. The working chair should be lifting and swivel, adjustable in height and angle of inclination of the seat and back, as well as the distance of the back from the front edge of the seat, while the adjustment of each parameter should be independent, easy to carry out and have a secure fit.

Occupational safety

A dangerous factor or industrial hazard is a factor whose impact under certain conditions leads to trauma or other sudden, severe deterioration of health of the worker.

A harmful factor or industrial health hazard is a factor, the effect of which on a worker under certain conditions leads to a disease or a decrease in working capacity.

1.4.1 Analysis of harmful and dangerous factors that can create object of investigation

The object of investigation is Zircaloy with Silicon-Carbide coating. Zircaloy with Silicon-Carbide coating cannot create harmful and dangerous factors by itself, but when it used in nuclear power plant it could activated by neutron. In this case we have harmful factor of increased level of ionizing radiation.

1.4.2. Analysis of harmful and dangerous factors that can arise at workplace during investigation

The working conditions in the workplace are characterized by the presence of hazardous and harmful factors, which are classified by groups of elements: physical, chemical, biological, psychophysiological. The main elements of the production process that form dangerous and harmful factors are presented in Table 1.

Table 5.1 – Possible hazardous and harmful factors

Factors (GOST 12.0.003-2015)	**Work stages**			**Legal documents**
	Development	Manufacture	Exploitation	
1. Deviation of microclimate indicators	+	+	+	Sanitary rules 2.2.2 / 2.4.1340–03. Sanitary and epidemiological rules and regulations "Hygienic requirements for personal electronic computers and work organization." Sanitary rules 2.2.1 / 2.1.1.1278–03. Hygienic requirements for natural, artificial and combined lighting of residential and public buildings. Sanitary rules 2.2.4 / 2.1.8.562–96. Noise at workplaces, in premises
2. Excessive noise		+	+	
3.Increased level of electromagnetic radiation	+	+	+	
4.Insufficient illumination of the working area		+	+	

				of residential, public buildings and in the construction area. Sanitary rules 2.2.4.548–96. Hygienic requirements for the microclimate of industrial premises.
5. Abnormally high voltage value in the circuit, the closure which may occur through the human body	+	+	+	Sanitary rules GOST 12.1.038-82 SSBT. Electrical safety. Maximum permissible levels of touch voltages and currents.
Laser Radiation				Laser safety. General safety requirements for development and operation of laser products. GOST 31581-2012

The following factors effect on person working on a computer:

- physical:
- temperature and humidity;
- noise;
- static electricity;
- electromagnetic field of low purity;
- illumination;
- presence of radiation;
- psychophysiological:
- psychophysiological dangerous and harmful factors are divided into:
- physical overload (static, dynamic)
- mental stress (mental overstrain, monotony of work, emotional overload).

Deviation of microclimate indicators

The air of the working area (microclimate) is determined by the following parameters: temperature, relative humidity, air speed. The optimum and permissible values of the microclimate characteristics are established in accordance with [2] and are given in Table 2.

Table 5.2 - Optimal and permissible parameters of the microclimate

Period of the year	**Temperature, ^{C}**	**Relative humidity,%**	**Speed of air movement, m/s**
Cold and changing of seasons	23-25	40-60	0.1
Warm	23-25	40	0.1

Excessive noise

Noise and vibration worsen working conditions, have a harmful effect on the human body, namely, the organs of hearing and the whole body through the central nervous system. It results in weakened attention, deteriorated memory, decreased response, and increased number of errors in work. Noise can be generated by operating equipment, air conditioning units, daylight illuminating devices, as well as spread from the outside. When working on a PC, the noise level in the workplace should not exceed 50 dB.

Increased level of electromagnetic radiation

The screen and system blocks produce electromagnetic radiation. Its main part comes from the system unit and the video cable. According to [2], the intensity of the electromagnetic field at a distance of 50 cm around the screen along the electrical component should be no more than:

- in the frequency range 5 Hz - 2 kHz - 25 V / m;
- in the frequency range 2 kHz - 400 kHz - 2.5 V / m.
- The magnetic flux density should be no more than:
- in the frequency range 5 Hz - 2 kHz - 250 nT;
- in the frequency range 2 kHz - 400 kHz - 25 nT.

Abnormally high voltage value in the circuit

Depending on the conditions in the room, the risk of electric shock to a person increases or decreases. Do not operate the electronic device in conditions of high humidity (relative air humidity exceeds 75% for a long time), high temperature (more than 35 ° C), the presence of conductive dust, conductive floors and the possibility of simultaneous contact with metal components connected to the ground and the metal casing of electrical equipment. The operator works with electrical devices: a computer (display, system unit, etc.) and peripheral devices. There is a risk of electric shock in the following cases:

- with direct contact with current-carrying parts during computer repair;
- when touched by non-live parts that are under voltage (in case of violation of insulation of current-carrying parts of the computer);
- when touched with the floor, walls that are under voltage;
- short-circuited in high-voltage units: power supply and display unit.

Upper limits for values of contact current and voltage

	Voltage, V	Current, mA
Alternate, 50 Hz	2	0.3
Alternate, 400 Hz	3	0.4
Direct	8	1.0

Insufficient illumination of the working area

Light sources can be both natural and artificial. The natural source of the light in the room is the sun, artificial light are lamps. With long work in low illumination conditions and in violation of other parameters of the illumination, visual perception decreases, myopia, eye disease develops, and headaches appear.

According to the standard, the illumination on the table surface in the area of the working document should be 300-500 lux. Lighting should not create glare on the surface of the monitor. Illumination of the monitor surface should not be more than 300 lux.

The brightness of the lamps of common light in the area with radiation angles from 50 to 90° should be no more than 200 cd/m, the protective angle of the lamps should be at least 40°. The safety factor for lamps of common light should be assumed to be 1.4. The ripple coefficient should not exceed 5%.

Laser Radiation

Laser safety refers to the safe design, operation and implementation of lasers to minimize the risk of laser accidents, especially those involving eye injuries. The lasers are dangerous because a small amount of laser radiations can lead to serious and permanent eye injuries, the sale and usage of lasers is typically subject to government regulations. Laser radiation was classified according to the power and the wave length. These classifications help to manage and control the risk of laser injuries. The injuries could happen because of two main effects, firstly the thermal effect and secondly the photo chemical effect. Moderate and high-power lasers are potentially hazardous because they can burn the skin. While moderate laser power can cause eye injuries also the high power laser can cause burn to the skin. Some recommendations must be followed to avoid the hazard during using laser radiation devices such as labeling lasers with specific warnings, and wearing laser safety goggles when operating lasers.

Laser products are classified into four hazard classes depending on the radiation generated.

Class 1. Laser products that are safe under the intended operating conditions.

Class 2. Laser products that generate visible radiation in the wavelength range from 400 to 700 nm. Eye protection is provided by natural reactions, including the blink reflex.

Class 3A. Laser products are safe for viewing with the unprotected eye. For laser products emitting radiation in the wavelength range of 400 to 700 nm, protection is provided by natural reactions, including the blink reflex. For other wavelengths, the hazard to the unprotected eye is no greater than for class 1.

Direct observation of the beam emitted by Class 3A laser products with optical instruments (e.g. binoculars, telescope, microscope) can be hazardous.

Class 3B. Direct observation of such laser products is always dangerous. Visible scattered radiation is usually harmless.

Conditions for safe observation of diffuse reflection for laser products of class 3B in the visible area: the minimum distance for observation between the eye and the screen is 13 cm, the maximum observation time is 10 s.

Class 4. Laser products emitting hazardous stray radiation. They can cause skin damage and also create a fire hazard. Special care should be taken when using them.

Indicate here hazard class of your laser: class 3A

Laser Power	Wavelength
150 w	650 nm

1.4.3 Justification of measures to reduce the levels of exposure to hazardous and harmful factors on the researcher

Deviation of microclimate indicators

The measures for improving the air environment in the production room include: the correct organization of ventilation and air conditioning, heating of room. Ventilation can be realized naturally and mechanically. In the room, the following volumes of outside air must be delivered:

- at least 30 m ^{3} per hour per person for the volume of the room up to 20 m ^{3} per person;
- natural ventilation is allowed for the volume of the room more than 40 m ^{3} per person and if there is no emission of harmful substances.

The heating system must provide sufficient, constant and uniform heating of the air. Water heating should be used in rooms with increased requirements for clean air.

The parameters of the microclimate in the laboratory regulated by the central heating system, have the following values: humidity 40%, air speed 0.1 m / s, summer temperature 20-25 ° C, in winter 13-15 ° C. Natural ventilation is provided in the laboratory. Air enters and leaves through the cracks, windows, doors. The main disadvantage of such ventilation is that the fresh air enters the room without preliminary cleaning and heating.

Excessive noise

In research audiences, there are various kinds of noises that are generated by both internal and external noise sources. The internal sources of noise are working equipment, personal computer, printer, ventilation system, as well as computer equipment of other engineers in the audience. If the maximum permissible conditions are exceeded, it is sufficient to use sound-absorbing materials in the room (sound-absorbing wall and ceiling cladding, window curtains). To reduce the noise penetrating outside the premises, install seals around the perimeter of the doors and windows.

Increased level of electromagnetic radiation

There are the following ways to protect against EMF:

– increase the distance from the source (the screen should be at least 50 cm from the user);
– the use of pre-screen filters, special screens and other personal protective equipment.

When working with a computer, the ionizing radiation source is a display. Under the influence of ionizing radiation in the body, there may be a violation of normal blood coagulability, an increase in the fragility of blood vessels, a decrease in immunity, etc. The dose of irradiation at a distance of 20 cm to the display is 50 μrem

/ hr. According to the norms [2], the design of the computer should provide the power of the exposure dose of x-rays at any point at a distance of 0.05 m from the screen no more than 100 μR / h.

Fatigue of the organs of vision can be associated with both insufficient illumination and excessive illumination, as well as with the wrong direction of light.

Abnormally high voltage value in the circuit

Measures to ensure the electrical safety of electrical installations:

- disconnection of voltage from live parts, on which or near to which work will be carried out, and taking measures to ensure the impossibility of applying voltage to the workplace;
- posting of posters indicating the place of work;
- electrical grounding of the housings of all installations through a neutral wire;
- coating of metal surfaces of tools with reliable insulation;
- inaccessibility of current-carrying parts of equipment (the conclusion in the case of electroporating elements, the conclusion in the body of current-carrying parts).

Insufficient illumination of the working area

Desktops should be placed in such a way that the monitors are oriented sideways to the light openings, so that natural light falls mainly on the left.

Also, as a means of protection to minimize the impact of the factor, local lighting should be installed due to insufficient lighting, window openings should be equipped with adjustable devices such as blinds, curtains, external visors, etc.

Laser radiation

The design of laser products, regardless of their hazard class and, if necessary, personal protective equipment must ensure the safety of people and exclude the possibility of unauthorized exit of laser radiation of any wavelength, as well as other related harmful factors outside the working area

The laser product must have protective devices to prevent unauthorized exposure of personnel to laser radiation exceeding the permissible emission limit for class 1, as well as safety interlocks to ensure safety during maintenance and operation.

Safety interlocks must be capable of shutting off the supply of hazardous electrical voltage to the laser product or its component parts. The possibility of generating laser radiation in the event of accidental disabling of interlocks must be excluded.

Any part of the protective device that, when removed or displaced, could allow personnel to access laser radiation above the permissible emission limit for class 1, must be labeled: "Caution! When opening - laser radiation".

In addition, depending on the hazard class of the laser product, the labels must additionally be labeled:

if the level of laser radiation does not exceed the permissible radiation limit for class 2: "Do not look into the beam";

if the level of laser radiation does not exceed the permissible emission limit for class 3A: "Do not look into the beam and do not observe directly with optical instruments";

if the level of laser radiation does not exceed the permissible radiation limit for class 3B: "Avoid exposure to the beam";

if the level of laser radiation exceeds the permissible emission limit for class 3B: "Avoid exposure of eyes or skin to direct or scattered radiation."

Laser products of classes 3A, 3B and 4 must have visual and / or audible laser warning devices.

Laser products of classes 3A, 3B and 4 must be equipped with a control key. The key must be removable and the laser product should not function if it is missing.

Class 3B and 4 laser products are generally required to be remotely controlled.

Shields should be used as laser shields for Class 3A, 3B and 4 lasers. The screens should be made of a material that is fire-resistant and impervious to laser radiation and should maximally cover the zone of interaction of the laser beam with the target.

As the most effective means of protecting personnel when working with class 4 laser products, special technological booths should be used.

Workplaces must be designed so that personnel are not exposed to laser radiation or that the radiation does not exceed the class 1 radiation exposure limit.

Laser products, except for classes 1, 2 and 3A, as a rule, must be operated in specially designated areas or can be located in an open space on the foundations or platforms of vehicles.

5.1 Ecological safety

5.1.1 Analysis of the impact of the nuclear power plant on the environment

Most nuclear power plants release gaseous and liquid radiological effluents into the environment, which must be monitored. Civilians living within 80 km of a nuclear power plant typically receive about 0.1 μSv per year.

All reactors are required to have a containment building in according to international requirements. The walls of containment buildings are several feet thick and made of concrete and therefore can stop the release of any radiation emitted by the reactor into the environment

Large volumes of water are used during the process of nuclear power generation. The uranium fuel inside reactors undergoes induced nuclear fission which releases great amounts of energy that is used to heat water. The water turns into steam and rotates a turbine, creating electricity. Nuclear plants are built near bodies of water.

All possible impact of nuclear power plant on environment is greatly reduced in operating regime by many safety precautions means. The most danger of nuclear energy come because of different sorts of disaster.

5.1.2 Analysis of the environmental impact of the research process

Process of investigation itself in the thesis do not have essential effect on environment. One of hazardous waste is fluorescent lamps. Mercury in fluorescent lamps is a hazardous substance and its improper disposal greatly poisons the environment.

Outdated devices go to an enterprise that has the right to process wastes. It is possible to isolate precious metals with a purity in the range of 99.95–99.99% from computer components. A closed production cycle consists of the following stages: primary sorting of equipment; the allocation of precious, ferrous and non-ferrous metals and other materials; melting; refining and processing of metals. Thus, there is an effective disposal of computer devices.

5.1.3 Justification of environmental protection measures

Pollution reduction is possible due to the improvement of devices that produces electricity, the use of more economical and efficient technologies, the use of new methods for generating electricity and the introduction of modern methods and methods for cleaning and neutralizing industrial waste. In addition, this problem should be solved by efficient and economical use of electricity by consumers themselves. This is the use of more economical devices, as well as efficient regimes of these devices. This also includes compliance with production discipline in the framework of the proper use of electricity.

Simple conclusion is that it is necessary to strive to reduce energy consumption, to develop and implement systems with low energy consumption. In modern computers, modes with reduced power consumption during long-term idle are widely used.

5.2 Safety in emergency

5.2.1 Analysis of probable emergencies that may occur at the workplace during research

The fire is the most probable emergency in our life. Possible causes of fire:

- malfunction of current-carrying parts of installations;
- work with open electrical equipment;
- short circuits in the power supply;
- non-compliance with fire safety regulations;
- presence of combustible components: documents, doors, tables, cable insulation, etc.
- Activities on fire prevention are divided into: organizational, technical, operational and regime.

5.2.2 Substantiation of measures for the prevention of emergencies and the development of procedures in case of emergencies

Organizational measures provide for correct operation of equipment, proper maintenance of buildings and territories, fire instruction for workers and employees, training of production personnel for fire safety rules, issuing instructions, posters, and the existence of an evacuation plan.

The technical measures include compliance with fire regulations, norms for the design of buildings, the installation of electrical wires and equipment, heating, ventilation, lighting, the correct placement of equipment.

The regime measures include the establishment of rules for the organization of work, and compliance with fire-fighting measures. To prevent fire from short circuits, overloads, etc., the following fire safety rules must be observed:

elimination of the formation of a flammable environment (sealing equipment, control of the air, working and emergency ventilation);

- use in the construction and decoration of buildings of non-combustible or difficultly combustible materials;

- the correct operation of the equipment (proper inclusion of equipment in the electrical supply network, monitoring of heating equipment);
- correct maintenance of buildings and territories (exclusion of the source of ignition - prevention of spontaneous combustion of substances, restriction of fireworks);
- training of production personnel in fire safety rules;
- the publication of instructions, posters, the existence of an evacuation plan;
- compliance with fire regulations, norms in the design of buildings, in the organization of electrical wires and equipment, heating, ventilation, lighting;
- the correct placement of equipment;
- well-time preventive inspection, repair and testing of equipment.

In the case of an emergency, it is necessary to:

- inform the management (duty officer);
- call the Emergency Service or the Ministry of Emergency Situations - tel. 112;
- take measures to eliminate the accident in accordance with the instructions.

5.3 Conclusion

In this section about social responsibility the hazardous and harmful factors were revealed. All necessary safety measures and precaution to minimize probability of accidents and traumas during investigation are given.

Possible negative effect on environment were given in compact form describing main ecological problem of using nuclear energy.

It could be stated that with respect to all regulations and standards, investigation itself and object of investigation do not pose special risks to personnel, other equipment and environment.

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