



Ain Shams University
Faculty of Science
Physics Department

***Investigation of New Stainless Steels Developed
for Industrial and Nuclear Applications***

Thesis

Submitted for Fulfill the Requirements of

M.Sc. Degree

In Nuclear Physics

By

Ahmed Said Mohamed Tageldin Mohamed

B.Sc. in Physics

Supervisors

Prof. / Samir Ushah El-Kameesy

Professor of Nuclear Physics
Ain Shams University

Prof. / Mamdouh Mahmoud Eissa

Professor of Steel & Ferroalloys
Technology (CMRDI)

Dr / Elsayed Salama Ahmed

Associate Professor of Nuclear Physics
Ain Shams University

2017



Ain Shams University
Faculty of Science
Physics Department

Degree: M.Sc. in Nuclear Physics.

Title: *Investigation of New Stainless Steels Developed for
Industrial and Nuclear Applications.*

Name: Ahmed Said Mohamed Tageldin Mohamed.

Thesis Supervisors:

Signature

Prof. / Samir Ushah El-Kameesy

Physics Department, Faculty of Science,
Ain Shams University

.....

Prof. / Mamdouh Mahmoud Eissa

Central Metallurgical Research Institute (CMRD)

.....

As. Prof. / El-Sayed Salama Ahmed

Physics Department, Faculty of Science,
Ain Shams University

.....



Ain Shams University
Faculty of Science
Physics Department

Name: Ahmed Said Mohamed Tageldin Mohamed

Degree: M.Sc. in Nuclear Physics.

Department: Physics.

Faculty: Science.

University: Ain Shams.

Graduation date: 2006, Ain Shams University.

Registration date: 10/11/2014

Grant date: / / 2017

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

"وَأَنْزَلْنَا الْحَدِيدَ فِيهِ بَأْسٌ شَدِيدٌ

وَمَنْفَعٌ لِلنَّاسِ".

صدق الله العظيم

(الحديد: الآية 25)

CONTENTS

CONTENTS

CONTENTS

Title	Page
Contents	1
Acknowledgement	3
List of Tables	4
List of Figures	5
List of Abbreviations	7
List of Symbols	9
Abstract	10
CHAPTER 1	Introduction and Previous Work
1.1.Introduction	12
1.2.Previous Work	13
1.3.Aim of The Present Work	22
CHAPTER 2	Stainless Steel as a Reactor Material
2.1. Introduction	24
2.2. Stainless Steel for Reactor Fuel Cladding	24
2.3. Control Rod Cladding and Absorbing Materials	28
2.4. Pressure Vessel	29
2.5. Pipes and Valves	30
2.6.Steam Generators	32
2.7.Steel for Fusion Reactor System	35
CHAPTER 3	Experimental Setups
3.1.Samples Preparation	39
3.2.Chemical Analysis	40
3.3.Optical Microscope Observation	41
3.4.Mechanical Properties	41
3.4.1. Vickers hardness measurements	41
3.4.2. Tensile properties determination	42
3.4.3. Impact energy absorption	44
3.5.Density Measurements	45
3.6.Gamma Rays Attenuation Measurements	46
CHAPTER 4	Results and Discussion
4.1.Chemical Analysis	48

CONTENTS

4.2. Microstructure	48
4.2.1. Schaeffler diagram	48
4.2.2. Optical microscopy observation	51
4.3. Mechanical Properties	54
4.4. Gamma Ray Attenuation Properties	59
4.5. Neutron Attenuation Properties	67
Conclusion	69
References	71
Publications	78
Arabic Summary	I

ACKNOWLEDGEMENT

Acknowledgement

First and above all, Author bow head thanking “**Allah**” for helping and inspiring to accomplish all this work.

Author is deeply grateful to **Prof. Samir Ushah El kameesy**, Professor of Nuclear Physics, Ain Shams University, for providing this opportunity to work under his esteemed guidance, for suggesting the work and supervising it, for useful comments and helping during the course of this work. Under his supervision I learned how to overcome many difficulties in my work. I also wish to express profound gratitude for his constant encouragement and critical discussions throughout this research program and during the preparation of this thesis.

Author would like to express his sincere gratitude to **Prof. Mamdouh Mahmoud Eissa**, Professor of Steel & Ferroalloys Technology (CMRDI). This work would not have been possible without his guidance, support and encouragement. For his effective supervision, helpful comments, and the extensive time he devoted to this work, providing many facilities during preparation and experimental measurements, and scientific supervision that helped to accomplish this study.

Author owes a great debt of gratitude to the completion of this work to **As. Prof / ElSayed Salama Ahmed**, Associate professor of Nuclear Physics, Ain Shams University, for his supervision, advice, and crucial contribution from the very early stage of this research by his fruitful discussion throughout this work. Above all and the most needed, he provided me unflinching encouragement and support in various ways.

List of Tables

<i>Table</i>	<i>Description</i>	<i>Page</i>
Table (4.1)	Chemical composition and density of the studied stainless steels alloys	49
Table (4.2)	Chromium and nickel equivalent values for the studied stainless steel alloys	50
Table (4.3)	Mechanical properties of Tungsten stainless steel samples	58
Table (4.4)	14 MeV neutron cross sections of the studied stainless steel alloys	68

List of Figures

<i>Figure</i>	<i>Description</i>	<i>Page</i>
Fig (2.1)	Stainless steels distribution in Boiling Water Reactor (BWR)	25
Fig (2.2)	Stainless steels distribution in Pressurized Water Reactor (PWR).	25
Fig (2.3)	The reactor pressure vessel.	30
Fig (2.4)	Typical shape of stainless steel reactor piping.	31
Fig (2.5)	Different types of reactor valves.	32
Fig (2.6)	Schematic of a vertical steam generator.	34
Fig (2.7)	The horizontal shape of steam generator.	34
Fig (2.8)	Schematic diagram of fusion reactor.	36
Fig (3.1)	The pilot plant induction furnace used in melting of different investigated steels.	40
Fig (3.2)	Spectrographic analyzer (SPGA) used to analyze the investigated steels.	40
Fig (3.3)	Image analyzer device.	41
Fig (3.4)	Hardness and micro-hardness testing machine.	42
Fig (3.5)	Standard tension test specimen, ASTM E-8.	43
Fig (3.6)	SHIMADZU Tensile Testing Machine.	43
Fig (3.7-a)	Dimensions of Charpy-V impact test specimens, machined according to standard.	44
Fig (3.7-b)	Impact testing machine.	44
Fig (3.8)	Experimental setup of gamma ray narrow beam transmission method.	46
Fig (4.1)	Shaeffler diagram for the investigated stainless steel alloys.	50
Fig (4.2-a:f)	Optical microscope observation of the studied stainless steel	51-54

	alloys.	
Fig (4.3)	Examples of the prepared tensile samples.	54
Fig (4.4)	Examples of the prepared impact samples.	55
Fig (4.5)	Hardness variation of the investigated stainless steel alloys.	56
Fig (4.6)	Yield strengths at room temperature of the investigated stainless steel alloys.	56
Fig (4.7)	Ultimate tensile strength at room temperature of the investigated stainless steel alloys.	57
Fig (4.8)	Elongation at room temperature of the investigated stainless steel alloys.	57
Fig (4.9)	Impact at room temperature of the investigated stainless steel alloys.	58
Fig (4.10-a:f)	Attenuation curves of prepared stainless steel samples at different gamma ray energies.	59-62
Fig (4.11)	Gamma ray linear attenuation for the studied standard stainless steel.	63
Fig (4.12)	Half value layers of gamma ray for the studied stainless steels.	63
Fig (4.13-a:f)	Experimental and theoretical mass attenuation coefficients of the investigated samples as a function of gamma ray energies.	64-67

List of Abbreviations

Abbreviations	Description
AGR	Advanced gas-cooled reactor
AISI	American Iron and Steel Institute
ASME code	The American Society of Mechanical Engineers
BCC	Body center cubic crystal structure
BCT	body-centered tetragonal
BWR	Boiling Water Reactor
Ci	Curie (Activity unit)
CMRDI	Central metallurgical research institute
Cr	Chromium
dpa	displacements per atom
F/M	Ferritic/martensitic stainless steels
GIV reactors	Fourth generation of nuclear reactors
GTAW	Gas tungsten arc welding
HPGe	The Hyper Pure Germanium detector
HVL	The half value layer
Inconel	Nickel chromium alloy
ITER	International Thermo-nuclear Experimental Reactor
keV	Kilo-electron Volt
LFR	Lead-cooled reactor
LOCA	Loss of coolant accidents
MeV	Mega-electron Volt
Mox	Mixed oxide fuel is nuclear fuel that contains more than one oxide of fissile material, usually consisting of plutonium blended with natural uranium, reprocessed uranium, or depleted uranium
MPa	Mega Pascal

MSR	Molten salt reactor
Ni-Cr stainless steel	The stainless containing nickel and chromium
ODS Alloy	Oxide dispersion strengthened alloys
PCMI	Pellet cladding mechanical interaction
PWR	Pressurized Water Reactor
RBMK	High power channel-type reactor
RPV	Reactor pressure vessel
SCWR	Super critical water cooled reactor
SFR	Sodium-cooled fast reactor
SGs	Steam Generators
SiC	Silicon carbide
SMAW	Shielded metal arc welding
SPGA	Spectrographic analysis
SS	Stainless steel
TOKAMAK	Toroidal chamber with magnetic coils
TRISO	Tristructural isotropic fuel, a type of micro fuel particle consisting of a fuel kernel composed of uranium oxide (sometimes uranium carbide) in the center, coated with four layers of three isotropic materials
VHTR	Very high temperature reactor
VV-IWS	Vacuum Vessel In-wall Shield
wt	Weight
XRD	X-ray diffraction
α - Phase	Ferritic structure in stainless steel
γ - Phase	Austenitic structure in stainless steel

List of Symbols

<i>Symbol</i>	<i>Description</i>
μ	Linear attenuation coefficient.
$\sigma_{Exp.}$	The experimental mass attenuation coefficients.
$\sigma_{Theo.}$	The theoretical mass attenuation coefficients.
α	Alpha particle.
K	Kelvin temperature degree.
kWm^{-1}	Kilo-Watt per meter.
E	Energy.
mm	Millimeter.
ml	Milliliter.
kV	Kilo-Volt.
kg	Kilogram.
I_o	Initial intensity of radiation (gamma rays and neutrons).
I	Intensity of radiation after passing through thickness (gamma rays and neutrons).
x	Sample thickness.
W_i	Fractional weight of the element.
ρ	Density.
Σ_R	Macroscopic removal cross section.