FEASIBILITY STUDY OF ADOPTING AN AVAILABLE STANDARD AS A NATIONAL STANDARD FOR THE MANUFACTURE OF BOILERS IN SRI LANKA

Ranga Vijith Kumara Karawita

(128364 B)

Thesis submitted in partial fulfillment of the requirements for the degree
Master of Engineering

Department of Mechanical Engineering

University of Moratuwa
Sri Lanka

November 2018

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or institute of higher learning to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: .... Date:..............................

Mr. R V K Karawita

The above candidate has carried out research for the Master's Thesis under my supervision.

Signature: .... Date: ....

Prof. K K C K Perera
Vice Chancellor,
University ofMoratuwa.

The above candidate has carried out research for the Master's Thesis under my supervision

Signature: .... Date: ....

Dr. J G AS Jayasekara
Senior Lecturer,
Department of Mechanical Engineering,
University of Moratuwa

ABSTRACT

As a result of several boiler explosions took place in the recent past that have been broadly discussed in Chapter 1 of this thesis, a need of a standard for the manufacture of boilers in Sri Lanka was arisen. Even though such codes have already been formulated, those are not practicable. Mainly the materials proposed for the shell are very rarely found in the local market. Therefore, in this research project, minimum and essential requirements for the manufacture of boilers and applicability of both specified materials and alternatively proposed materials which affect the construction of boilers were analysed. The main objective of the project was to carry out a feasibility study for adopting an existing standard as national standard. Within the identified scope the objectives of the research were to:

identify material requirements for the shell;

identify material requirements for the tube plates; and

identify material requirements for the man hole and hand hole.

Data collection was through open discussion with the manufacturers and statistics of the Labour Department. As of the findings of Chapter **8**, for a given steam boiler, the material specified in the standard and the proposed equivalent martial A36 as well, can be used for the shell, tube plates and man/hand holes.In addition to that, to provide essential guidelines to boiler manufacturers as given in Boiler pressure part materials of Chapter **3** and Pressure vessel welding of Chapter**4** so that their manufacturing process is enhanced thereby, to streamline the boiler industry of the country with the national legislations thereby, to ensure a safer working environment for the operators thereby and to evaluate the standard requirements in comparison with the actual data of materials to be used for the above are the other objectives.

In furtherance to that, the adopted standard as such is going to be used as the base document of the law that will be enacted by the Department of Labour of Sri Lanka in order to regulate the boiler industry or manufacture of boilers in Sri Lanka. Since the standards are voluntary in nature, it is essential to make special provisions in order to get this enacted as a law which will be a part and parcel of the judicial system of the country while the same will enhance the boiler industry to be matured enough in order to be able to confront with the market challenges by avoiding technical barriers to trade (TBT). However, there are two main limitations in consideration of assistance to be derived from existing standards as, availability of specified materials in the Sri Lankan market and achieving the specified quality control and assurance of welding process. Keeping the above as constraints of this study and IBR as the standard identified, a material designated by ASTM as A 36 was identified for equivalence from the market. Studies can be extended up to manufacture of pressure vessels as future work.

Finally, this project will open another access for forward march of the country, to become a Newly Industrialized Country (NIC).

ACKNOWLEDGEMENT

Firstly, I would like to express my sincere gratitude to my advisors, Prof. K. K .C. K. Perera, Vice Chancellor, University of Moratuwa, Sri Lanka and Dr. Saliya Jayasekara, Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa, Sri Lanka for the continuous support of my MEng research for their patience, motivation, and immense knowledge.

Besides my advisors, I would like to express my special gratitude to Dr. L N Senaweera, former Director General, Sri Lanka Standards Institution for facilitating me to do the M Eng. in energy sector. His insightful comments, encouragement and hard questions insisted me to widen my research from various perspectives.

My sincere thanks also goes to Eng. M A Justin, Managing Director, Professionalmet Consultancy (Pvt.) Ltd., Eng. Rohith Fernando, Commissioner of Labour (Industrial Safety). Labour Department of Sri Lanka and Eng. Madhawa Perera, consulting engineer who facilitated me in literature survey and data collection, for their support in those activities.

Without their precious support it would not be possible to conduct this research. Further, I would appreciate everybody, who helped me in numerous ways at different stages of the research which was of utmost importance in bringing out this effort a success.

Last but not the least, I take this opportunity to express my gratitude to my beloved wife and two children for bearing up enormous burden during the period of my post graduate studies.

TABLE OF CONTENTS

DECLARATION..i
ABSTRACT..ii
ACKNOWLEDGEMENT...iii
TABLE OF CONTENTS...iv
LIST OF FIGURES...viii
LIST OF TABLES...ix
LIST OF ABBREVIATIONS..x
1 INTRODUCTION AND BOILER STANDARDS..1
1.1 Background..1
1.2 Justification..2
1.3 Aim and objectives..3
1.4 Methodology..3
1.5 Feasibility assessment on availability of adoptable standards, pressure vessel material and manufacturing (welding)...5
2 PRESSURE VESSEL DESIGN CODES...,7
2.1 Introduction..7
2.2 Scope..7
2.3 Definitions..7
2.3.1Boiler: 7
2.3.2Pressure vessel:..7
2.3.3Certification:..7
2.3.4Conformity: 7
2.3.5Construction: 8
2.3.6Contracting party: 8
2.3.7Designer:..8
2.3.8Examination:..8
2.3.9Inspection: 8
2.3.10Inspecting authority: 8
2.3.11Inspecting engineer:..8
2.3.12 Manufacturer of boilers: 8
2.3.13 Maximum allowable pressure: 8
2.3.14 Owner: 9

2.3.15 Qualification: 9
2.3.16 Regulations: 9
2.3.17 Safety accessories: 9
2.3.18 Testing: 9
2.3.19 User: 9
2.3.20 Third party inspector: 9
2.4 Classification of boilers 10
2.5 Design 10
2.5.1 Engineering drawings 10
2.5.2 Design calculations and requirements 11
2.5.3 Furnaces 19
2.6 Manufacture 23
2.6.1 Materials of construction 23
2.6.2 Accessories 25
2.6.3 Boiler safety control system 33
2.6.4 Rolling margin 34
2.6.5 Construction and workmanship 35
2.7 Inspection and testing 39
2.7.1 Inspection and testing of boiler during manufacture 39
2.8 Marking 42
2.8.1 General 42
2.8.2 Marking required 42
3 BOILER PRESSURE PART MATERIALS 43
3.1 Design calculation (sample) 44
3.1.1 Design of pressure parts with a material specified in the standard 44
3.1.2 Design of pressure parts with a material specified in the standard 48
4. PRESSURE VESSEL WELDING 53
4.1 Introduction 53
4.2 Welding processes 53
5 ISSUES IN EMPLOYING ACCREDITEDWELDERS 60
6 QUALITY ASSURANCE 62
6.1 Introduction 62
6.2 Application and Scope 62
6.3 Welder's responsibility 62

6.4 Pressure welder's qualification tests....63
6.5 Stamping of work....65
6.6 Manufacturers and contractors responsibility....66
6.7 Repairs to Boilers and Pressure Piping....67
6.8 Classification of pressure piping....68
6.9 Welding of Pressure Piping....68
6.10 Inspection of Pressure Piping....70
6.11 Inspection General....70
6.12 Testing of welders and procedures....71
6.13 Welding procedure qualification (WPQ) of A36 steel plates....71
6.13.1 General....71
6.13.2 Procedure Preparation of the Specimens....76
6.13.3 Bend Testing....77
7 LEGISLATION AND FINDINGS....84
7.1 Introduction....84
7.2 Literature review....84
7.3 Feasibility Study....84
7.4 Developing an adopted standard (draft) based on the identified criteria....84
7.5 Circulation of the draft standard among interested parties....85
7.6 Analysing the received comments....85
7.7 Finalizing the standard....85
7.8 Completion of the standard adoption process....85
7.9 Enactment as a law of the country....85
7.10 Implementation....86
7.11 Introduction to boiler failure analysis....86
7.11.1 A practical example of boiler failure analysis....86
7.11.2 Analysis of alternatively suggested methods in lieu of adopted standard requirements....86
7.12 A preliminary analysis of failure of a locally manufactured package boiler..86
7.12.1 Location:....86
7.12.2 Details of the boiler:....87
7.12.3 Objective....87
7.12.4 Preliminary observations....87
7.12.5 Secondary observations....89

7.12.6 Conclusions.. 90
7.13 Comparison of shell design with a material specified for and a material available in the market……………………………………………….................91
7.14 Comparison of tube plate design with a material specified and a material available in the Sri Lankan market…………………………………….............92
7.15 Comparison of man holes-hand holes door design with the material specified and a material available in the market...93
7.16 Analysis of root-cause for the boiler explosions...93
7.17 Cost analysis of imported boilers and locally manufactured boilers................94
7.18 Alternative materials and their properties...94
8 CONCLUSION AND FUTURE WORK...96
REFERENCES...99
Appendix A INSPECTION FORMS...100
Appendix B HOT WATER BOILER PROCESS OUTLOOK DIAGRAM.......118

LIST OF FIGURES

.

Figure 2.1-Compensation for branch..16

Figure 2.2-Relationship between furnace diameter and permissible heat input..........20

Figure 4.1-Gas cooled and water cooled GTAW welding torches..............................54

Figure 4.2-Tungsten electrodes...57

Figure 4.3-Welding positions 1G and 3G...58

Figure 4.4-The effect of shielding gas composition on the weld penetration..............59

Figure 6.1-The Heat Affected Zone is the immediate area surrounding the weld 74

Figure 6.2-The Heat Affected Zone...76

Figure 6.3-The mechanical wraparound bend test...77

Figure 6.4-The reduced section tensile test 78

Figure 6.5-Images of failed bend specimen..79

Figure 6.6-Dye penetrant inspection images..80

Figure 6.7-Schematic of boiler showing critical inspection points..............................80

Figure 6.8-Inspection area 1.3, 1.4 and 1.6 81

Figure 6.9-Inspection area 4.4 and 5.4...82

Figure 6.10-Inspection area 7.1 and 7.2 82

Figure 6.11-Inspection area 1.5 and 6.2 83

LIST OF TABLES

Table 1.1 - Reported incidents to the department of labour 1
Table 2.1 - Classification of boilers(Shell boilers) 10
Table 2.2 - Material Selection for boiler parts and fittings 24
Table 2.3 - Material selection for hot water boiler parts and fittings 25
Table 2.4 - Value of constant ‘C’ 27
Table 2.5 - Schedule of percentage of rolling weight tolerances for boiler plates 35
Table 3.1 - Equivalents of Carbon Steel Qualities 43
Table 3.2 - Comparison between plate thickness of A36 and IBR material 49
Table 3.3 - Comparison between plate thickness of A36 and IBR material 50
Table 3.4 - Comparison between plate thickness using A36 and IBR material 52
Table 4.1 - Typical Current Ranges for Different Wire Diameters in the GMAW 55
Table 4.2 - Tensile and Yield Strength of Base and Filler Metals 58
Table 6.1 - Process/Base Material/Position Combination of WP Specifications 72
Table 6.2 - Specifications for tensile and bend testing specimens 76
Table 7.1 - Comparison between plate thickness of local and IBR material 91
Table 7.2 - Comparison between plate thickness of local and IBR material 92
Table 7.3 - Comparison between plate thickness of local and IBR material 93
Table 7.4 - Physical, Mechanical and Chemical properties of A36 Steel plate 95

LIST OF ABBREVIATIONS

Abbreviation	Description
UTS	Ultimate Tensile Strength
AWS	American Welding Society
PWHT	Post Weld Heat Treatment
IACS	International Association of Classification Societies

1 INTRODUCTION AND BOILER STANDARDS

1.1 Background

In the recent past several boiler explosions have taken place in Sri Lanka and most of them have been reported to the Department of Labour of Sri Lanka[1]. Fatal accidents had occurred in the recent past as shown in Table **1.1**, due to those boiler explosions and they are mainly due to two reasons. As revealed with the assistance of the Department of Labour of Sri Lanka, the aforesaid two reasons are, lack of basic knowledge in designers and lack of qualified welders. Further the explosions had been linked to manufacturing defects and operational failures.

The remedial action to eliminate the root causes for the aforesaid problem would be formulation and implementation of a national standard for boilers.

Table 1.1 - Reported incidents to the department of labour(source: Statistics of the Department of Labour of Sri Lanka)

Year	**Locations**	**No. of Boilers exploded**	**No. of deaths or injuries**
2003	Dambulla&Batticallo	02	05 deaths
2006	Medirigiriya	01	02 deaths
2007	Batticallo	01	05 deaths
2008	Anuradhapura	01	01 death
2011	Badulla and Galle	02	03 died & 02 injured
2016	Kurunegala	02	01 died & 01 injured

In view of the manufacturing defects, it is revealed that the proper material selection with respect to specified mechanical and chemical properties is not carried out by the manufacturers in accordance with the information available in the Sri Lankan boiler industry[1], lack of awareness of the relevant standards[1] and non-availability of quality materials and/or qualified welders being the reasons.
According to the literature, the reasons for these are as follows:

Lack of quality materials or they are expensive[2],
Not following pressure vessel design calculations[2],

Lack of qualified welders[2],
High cost of getting services of qualified welders[2],
Lack of awareness of welding quality control and quality assurance[2],
Not conforming to any of the standards due to lack of legislations[2], and
Lack of responsibility and unawareness of risk factor[2].

In view of those explosions that have taken place due to manufacturing defects, the worldwide recognized strategic approach to tackle the problem is development of standards that provide specifications for manufacturing requirements of boilers and implementation of the same by enacting it as a law through the legal system of the country. This implies that there is a need for a boiler standard to be used at the design and manufacturing stage.

In the Sri Lankan context too, as the situation was worsened over the last decade, Sri Lanka Standards Institution, as the National Standards Body had made a proposal to the Department of Labour regarding formulation of the National Standards while they are in an urgent need to prescribe regulations under the National Legislation on Factory Ordinance with respect to manufacture and safe operation of boilers in order to prevent such disastrous explosions which sometimes cause multiple deaths.

In this context, it can be studied in identification of the manufacturing requirements with material selection according to the boiler class. Further analysis can be done on the cost effectiveness of replacing the current methods of manufacture with the available best optimal technologies.

1.2 Justification

Boiler is defined as an assembly intended for generation of steam or hot water above atmospheric pressure. Typically, vertical boilers, horizontal boilers, hot water boilers (water heaters), steam boilers and thermic heaters are the main types of boilers. In reality, boiler would be considered as a symbol of a Newly Industrialized Country(NIC)[3]. In other words, it is an indication of calibre of a NIC within which large scale manufacture of standardised boilers play a major role. India gives us such an example where the industry was regulated even before their independence, in 1920s[4]. However, in Sri Lanka, boilers up to the operating pressure of 25 bar(2.5N/mm^2) are only being manufactured while in case of hot water boilers or commonly known as water heaters, up to 2 million kCal/hr and temperature up to 175 °C are only being manufactured. However, no standard or code is being followed at present in manufacturing. Therefore, Sri Lankan boiler industry is at its initial stages where no legislated standard or guideline exists for that to be orientated towards such a state of NIC. In this process of standardization, it is intended to get a fruitful outcome of the form of an adopted standard as the National Standard which will be able to orientate the boiler industry towards that of a NIC. Further, it is needed to evaluate the standard requirements in comparison with the actual data of materials to be used in manufacturing boilers. Even though thermic heaters are also manufactured in Sri Lanka, that has been excluded herein so that later be addressed separately since the working fluid used in this case is not water and therefore the design and manufacture of the thermic heaters is different.

1.3 Aim and objectives

Aim of the research is to identify the feasibility of adopting an available standard as a National Standard for Boilers in order to effectively develop a practicable standard considering the availability of resources in Sri Lanka.

The objectives of the research are:
to identify the applicability of a national standard within the identified scope.
to identify the material requirements for the shell, tube plates, man holes and hand holes as specified in the adopted standard.
to evaluate the standard requirements in comparison with the actual data of materials to be used in manufacturing boilers.

1.4 Methodology

Proposed Scope for the Standard:

This Standard specifies the minimum and essential design, manufacturing, inspection, testing, marking requirements for boilers up to a maximum capacity of 10,000 kg (10 tons) of steam per hour from and at feed water temperature of 100 °C and steam outlet pressure of 1bar(1atm) and up to an operating pressure of 25 bar (2.5 N/mm^{2}or 362.5 psi). It also specifies criteria for the hot water boilers up to 2 million kCal/hr and temperature up to 175 °C [4]. Further a ‘Range of Application’ is classified, considering the current status of the Sri Lankan boiler industry as in Table **2.1** of

Chapter **2**.

During this study, in consultation with the Department of Labour, several national/international standards/codes were taken into consideration and identified the applicability of them within the identified scope. In this consideration, the standards' requirements against current industrial requirements with respect to the said materials above in 1.3, were compared and analysed. Finally, based on the findings of the research, a set of recommendations will be proposed in the form of an adoption for standardizing the boiler industry.

In analysing the material requirements, a market survey for availability of suitable materials was carried out. With the help of the Department of Labour, the information from manufacturers was obtained. Actual data of such materials were evaluated and presented in comparison with identified standard requirements. Then the equivalent material which complies with the requirements of a selected adoptable standard is suggested.

Since the standards are volunteer by nature, in order to regulate the boiler industry of the country, the adopted standard as such, is to be regarded as the base document of a legal frame work. This legal framework will be enacted by a parliament act of which the power of implementation will be vested on Department of Labour, solely. After this legalization process will be over, finally the industrialists and other stake holders will be facilitated by a fully legalized system where a safer working environment will be ensured for the boiler operators thereby.

In the event of implementation of the standard, there are three main approaches:

01. Through an international certification body, on which all the essential powers vested, on behalf of the Labour Department of Sri Lanka.
02. Based on a report prepared by an accredited testing body which will assess the design and report to the Labour Department of Sri Lanka.
03. Labour Department of Sri Lanka may implement the certification scheme by themselves solely, without any third party intervention.

However, the second approach would be considered as more practicable and fruit full in view of effectiveness and financial aspects as well.

Before this being implemented, department of labour will make aware the boiler industrialists and other stake holders of the industry. Inspecting engineer will have to play a major role in the implementation phase where he will be the decision maker at the user end.

An introduction to the chapters

Chapter 1 - Introduction and boiler standards: An introduction to the thesis as a whole in view of background, justification, aim, objectives, methodology and feasibility assessment is given.

Chapter 2 - Pressure vessel design codes: The design codes to be adopted as National Standards have been discussed.

Chapter 3 - Boiler pressure part materials: Materials to be used in pressure parts, either specified and alternatively selected materials and their properties have been discussed.

Chapter 4 - Pressure vessel welding: Welding process requirements have been discussed.

Chapter 5 - Issues in employing accredited welders: Practical problems confronted by the manufacturers in employing qualified welders have been discussed.

Chapter 6 - Quality Assurance: Quality assurance process of welding process have been discussed.

Chapter 7 - Legislation: Legal procedures to be followed by the manufacturers have been discussed

Chapter 8 - Summary of findings: Outcome of the feasibility study has been discussed.

Chapter 9 - Conclusion and future work: Conclusion in accordance with the findings and proposals for future work have been expressed.

1.5 Feasibility assessment on availability of adoptable standards, pressure vessel material and manufacturing (welding)

In view of the availability of an adoptable standard for the intended purpose, several standards were considered. There are two main areas of concerned, in this regard:

Availability of materials and other requirements specified in the standard

Existing standard by which majority of the boilers are covered

As discussed in Chapter **3**, requirements for the materials which are being used commonly in the Indian boiler industry are compiled (in view of physical and chemical properties) to the requirements of standards specifications of IS 2062(Indian S36 standards Specification). However, in accordance with the information given in the Table **3.1,** IS 2060 Grade A material properties are equivalent to **A 36**material properties (physical and chemical) and the same material is compatible with IBR specifications with respect to materials. A 36 is the commonly used material in the Sri Lankan boiler industry too. Therefore, one of the main reasons for selecting IBR as the adoptable standard is above said equivalence of IS 2060 Grade A and A 36.

The other main reason is high percentage of boiler imports from India. In accordance with the Import Export Control Department of Sri Lanka it has been as high as of 85 percent during the last decade. The Indian boiler manufacturers have been able to supply boilers for competitive prices with respect to the manufacturers of other countries due to the availability of required technology, large scale of manufacture and low cost of labours.

Therefore, the most suitable standard from which the assistance to be derived is IBR. However, since IBR is regarded as a regulatory measure in Indian Republic, the required assistance to be derived considering the non-violation of such regulatory requirements. Further the essential and minimum requirements also to be identified in deriving the necessary assistance. In accordance with the reported failures, it is quite evident that the thickness of materials (steel sheets) used for shell, tube plates, man holes and hand holes shall be standardised in view of eliminating them. Therefore, the minimum and essential requirements for those parts are mainly focused on.

Furthermore, in view of the quality control and quality assurance of welding process and thereby the weld, as discussed in Chapter **4** and Chapter **6**, welding procedure requirements for A 36 and that of mainly laid down in IBR are inline. Based on this approach, final decisions are arrived at, in adopting the standard. However, in case of definitions of some important vocabulary terms, assistance of **ISO 16528-1:2007** has been derived.

2 PRESSURE VESSEL DESIGN CODES

2.1 Introduction

In this standard, the manufacturing requirements and test methods for the following boiler types are specified:

Low Pressure – Max. Working pressure up to and including 10 barg (1 N/mm^2 or 145 psi) Medium Pressure– 10 barg(1 N/mm^2or 145 psi) $<$ working pressure $\leq$ 25 barg(2.5 N/mm^2 or 362.5 psi)

2.2 Scope

This Sri Lanka Standard specifies the minimum and essential design, manufacturing, inspection, testing and marking requirements for boilers up to a maximum capacity of 10,000 kg(10 tons) of steam per hour from feed water temperature of 100 °C and steam outlet pressure of 1bargand up to an operating pressure of 25barg(2.5 N/mm^2 or 362.5 psi). It also specifies criteria for the hot water boilers up to 2 million Kcal/hr and temperature up to 175 °C.

2.3 Definitions

For the purposes of this standard, the following terms and definitions shall apply:

2.3.1 Boiler

Assembly intended for generation of steam or hot water above atmospheric pressure [6]

2.3.2 Pressure vessel

Container designed and built to store gasses or liquids under pressure [6]

2.3.3 Certification

Procedure by which an inspecting authority or third party inspector gives written assurance that a product, process or service conforms to specified requirements [6]

2.3.4 Conformity

Fulfilment of specified requirements [6].

2.3.5 Construction

Processes that include design, material specification, manufacture, inspection, examination, testing and conformity assessment of boilers [6].

2.3.6 Contracting party

Individual or organization involved with construction of boilers and pressure vessels [5].

2.3.7 Designer

Organization or individual that performs design of boilers in compliance [5].

2.3.8 Examination

Activity carried out by qualified personnel using accepted procedures to assess that given products, processes or services are in conformity with the specified requirements [6].

2.3.9 Inspection:

Activity to check that the results of required testing or examinations comply with specified requirements [6].

2.3.10 Inspecting authority

Industrial Safety Division of the Department of Labour of Sri Lanka [6].

2.3.11 Inspecting engineer

A qualified engineer selected through an approved process for a specific inspection by the inspecting authority [6].

2.3.12 Manufacturer of boilers

An individual or a legal entity who is authorized for the construction of boilers in accordance withspecifications provided by the contracting party, andrequirements of this standard[6].

2.3.13 Maximum allowable pressure

Maximum pressure for which a boiler or a pressure vessel is permitted for safe operation [6].

2.3.14 Owner

An individual or organization having legal title to a specific boiler or a pressure vessel [5].

2.3.15 Qualification

Proof of suitability of an individual, process, procedure or service to full fill specified requirements [5].

2.3.16 Regulations

Rules promulgated by a government authority in accordance with legal statutes or directives [5].

2.3.17 Safety accessories

Devices designed to protect the boilers and pressure vessels against the allowable limits of pressure and temperature being exceeded [6]

NOTE: Such devices include

- Devices for direct pressure limitation, such as safety valves, bursting disc safety devices, fusible plugs,pressure relief systems.
- Limiting devices, which either activate the means for correction or provide for shutdown or lockout, such as pressure switches or temperature switches or fluid level switches.

Safety related measuring devices, controlling and regulating devices.

2.3.18 Testing

Activity carried out to determine, by specific procedures, that one or more characteristic of a product, process or service meet(s) one or more specified requirements [6].

2.3.19 User

Organization or individual using or operating specific boiler/boilers and/or pressure vessel/vessels [5].

2.3.20 Third party inspector

An individual or an organization that performs inspection of parts or components of a boiler on behalf of the inspecting authority when such inspection is not practicable for the inspecting engineer [5].

2.4 Classification of boilers

All the Boilers covered in this standard shall be classified as given in the Table 2.1 below [5].

Table 2.1 - Classification of boilers (shell boilers)

Classification	Range of application
Low Pressure	Max. Working pressure ofup to and including10 barg (1N/mm^2 or145 psi)
Medium Pressure	10 barg(1 N/mm^{2}or145 psi) <working pressure ≤ 25 barg(2.5 N/mm^{2}or362.5 psi)

2.5 Design

2.5.1 Engineering drawings [4] [5].

Detailed engineering drawings (the list given below) of the parts to be machined, fabricated, assembled and or the complete boiler shall be forwarded to the inspecting authority for approval before manufacturing. The scale of the drawings or prints shall be, in the case of medium pressure boilers not less than 1:20 and in the case of low pressure boiler not less than 1:10, showing the principal dimensions, a longitudinal section and an end view of the boiler bearing the works number of the boiler and the manufacturer's stamp.

In the case of water tube boilers, the foregoing scales shall apply to the main boiler drums only, but in addition a general arrangement drawing of the boiler to a scale of not less than 1:50 shall be provided.

The following Engineering drawings shall be forwarded

01. General arrangement drawing of the boiler showing the principal dimensions, sectional and end view of the boiler with location of all fittings and accessories.
02. End plates
03. Reversing chamber end plates

04. Welding details
05. Manhole / door
06. Mud hole/ door
07. Water level gauge assembly
08. Water level controller
09. Furnace and fire grate assembly (In case of Bio-mass boilers)
10. Dust control system (In order to meet CEA standards)
11. Arrangement of boiler tubes (Fire tubes or Water tubes)
12. Any other drawing as required by the inspecting authority

For hot water boilers, in general there are two types of design:

01. Shell and tube type design and
02. Coil type design

Typical hot water boiler systems consist of following units

- Hot water generator
- Expansion tank
- Circulation pump

2.5.2 Design calculations and requirements [4]

Minimum thickness of shell of the boiler

For temperatures at or below 454 °C allowable stress, R, shall be taken as the smaller of two values given in equation (2.1).

$$R = \frac{R_s}{2.7} \text{ or } \frac{R_y}{1.5} \tag{2.1}$$

Where,

R_s : Minimum specified tensile strength of steel at room temperature in N/mm^2

R_y : Yield point at temperature T in N/mm^2 where T is the working metal temperature

Minimum thickness of the shells under internal pressures hall be determined by equation (2.2)

$$t = (d \times P_w)/(2RE - P_w) + 1 \quad (2.2)$$

Where,

t : Thickness of Shell, in mm

d : Inside Diameter of Shell, in mm

P_w : Working Pressure, in N/mm^2

R : Minimum Tensile Stress for Plate, in N/mm^2

E : Weld Factor = 1 (if 100% X-Rayed)

Minimum thickness of the shells of boilers working pressure below 0.2 N/mm^2 shall be determined by equation(2.3

$$t = \frac{70D \times P_w}{SC} + 1.5 \quad (2.3)$$

Where,

t : Minimum thickness of shell plate, in mm

D : Maximum internal diameter in mm

P_w : Working Pressure, in N/mm2

S : Minimum tensile strength in N/mm2

C : Constant, C = 21 when stress is not relieved,

Constant, C = 23 when stress is relieved

NOTE:

The factor of safety of the shell shall not be less than 4 or the plate thickness be less than 9.5 mm

Calculation of the plates

Where boilers have a nest or nests of horizontal tubes, and there is a direct tension on the tube plates due to the direct load on the boiler ends or to tube plates acting as ties across the shell:

i) Each alternative tube in the outer vertical row of tubes shall be a stay tube.

ii) The thickness of tube plates and the spacing of the tubes shall be such that the effective area of the metal taking the load is sufficient to keep the stress within that allowed on the shell plate, as determined by the following formula:

$$t = \frac{400L \times P_w}{RJ} + 2 \tag{2.4}$$

Where,

t : Thickness of the tube plate, in mm

L : The radial distance of the centre of the outer row tube holes from the axis of the shell in mm

P_w : Working pressure, in N/mm^2

R : Minimum Tensile Stress in N/mm^2

J : Percentage strength of the plate through tube holes where J is given by equation (2.5)

$$J = \frac{100 \times (P - D)}{P} \tag{2.5}$$

Where,

P : Vertical pitch of tubes in mm

D : Diameter of the tube holes in mm

Manholes and other openings in shells

Thickness Calculation of Manholes & Hand Holes Door

The minimum calculated thickness of the door of the flat plate construction (i.e. Unstiffened made from one plate) shall be not less than that determined by the equation

(2.6) for circular door and equation (2.7) for elliptical door.

For a circular Door:

$$t = \sqrt{\frac{0.35P_w \times d^2 + w}{f}} \tag{2.6}$$

For an Elliptical Door:

$$t = \sqrt{\frac{0.35P_w \left(2 - \frac{a}{b}\right) \times a^2 + w}{f}} \tag{2.7}$$

Where,

t : Minimum calculated thickness of the flat door, in mm

P_w : Working pressure of boiler, in N/mm^2

d : Diameter of the opening to which the door is fitted, if rounded, in mm

w : Full load capacity of one stud effective stud area × design stress value at design temperature, in N

f : Maximum allowable stress of the plate at the design temperature, in N/mm^2

a : Minor axis of the opening to which the door is fitted if elliptical, in mm

b : Major axis of the opening to which the door is fitted if elliptical, in mm

NOTE:

Design stress of value of 50 N/mm^2may be used for carbon steel bolts for design temperature not exceeding 300 °C.

Manholes and other openings in shells shall be placed as far as possible from any seam. Wherever practicable, oval openings shall be arranged with the minor axis parallel with the longitudinal centreline of the boiler. In no case shall the perimeter of any opening exceed twice the longitudinal width of the opening.

Raised manhole frames, cover plates and joint bolts

Raised circular manhole frames not exceeding 400 mm in diameter shall not be less than 19 mm thick in all parts.

The circular cover plates and joint flanges for such frames shall be not less than 25 mm thickfor pressures not exceeding 0.827 N/mm^2

29 mm thick for pressures exceeding 0.827 N/mm^{2}but not exceeding 1.37 N/mm^2.

32 mm thick for pressure exceeding 1.37 N/mm^2 but not exceeding 1.724 N/mm^2.

For pressure exceeding 1.724 N/mm^2, raised circular manhole frames shall not be fitted.

The cover plates shall be secured by at least sixteen steel bolts not less than 25 mm diameter, such that the stress in the bolts due to steam pressure shall not exceed: -

34 N/mm^2 for 27 mm bolts.

41 N/mm^2 for 30 mm bolts.

44 N/mm^2 for 33 mm bolts.

For the purpose of calculation, the pressure shall be assumed to act on the whole area within the pitch circle of the bolts and the bolt area at the bottom of the screw thread shall be taken.

Compensation for openings in shells

Where the width of any opening (measured in a direction parallel to the longitudinal axis of the boiler) exceeds two-and-a-half times the thickness of the shell plate in mm plus 69 mm, compensation shall be provided.

a) Area to be compensated

   The area to be compensated shall be the product of the maximum width of the opening cut in the shell and the thickness of an unpierced seamless shell of similar material calculated by Equation (2.1)with constant C=35 for the same working pressure.

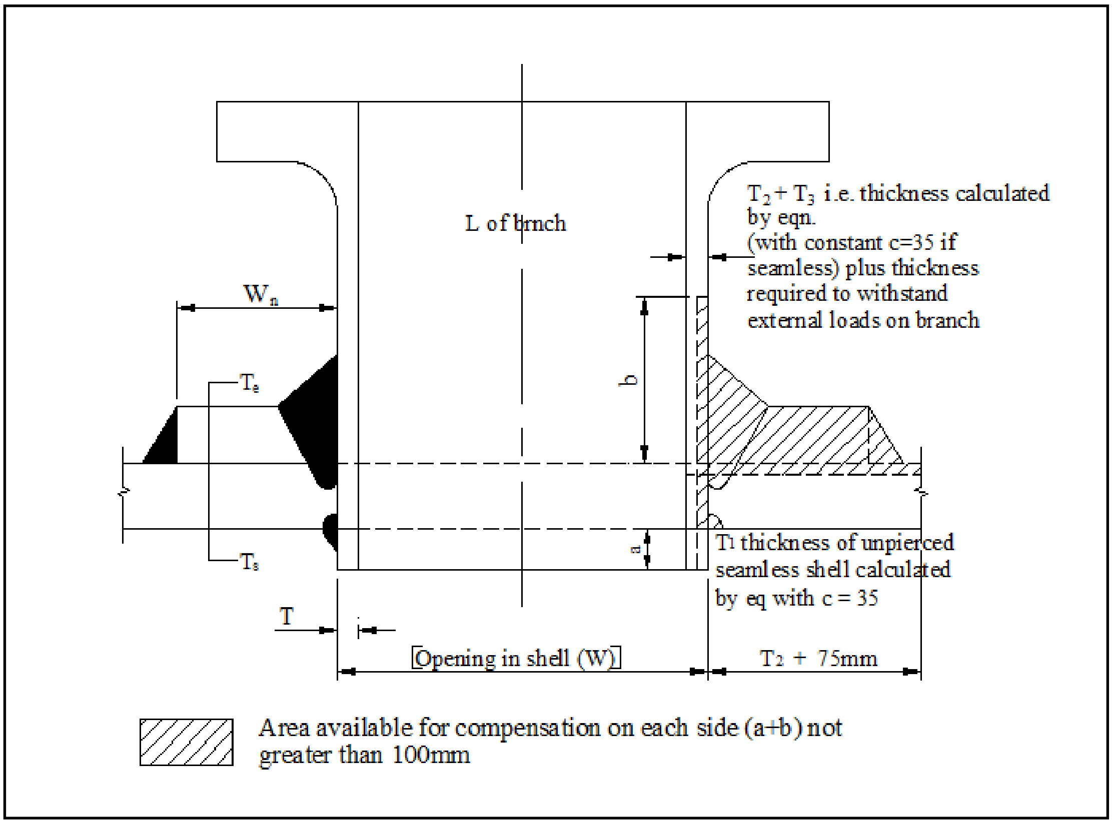


Figure 2.1 - Compensation for branch[4]

b) Compensating area

Compensation shall be considered adequate when the sum of the following areas is equal or more than the area to be compensated:

i) The area obtained by multiplying the difference between the actual thickness of the shell and the thickness required for an equivalent un-pierced seamless shell by a length 2(75mm+ T_s), where T_s is the actual thickness of the shell plate in mm.

ii) The net cross sectional area of the frame or pad, or in the case of a branch the cross sectional area of the wall of the branch minus the sectional area of a branch of the same bore having thickness equal to that calculated by Equation (2.2) for the same working pressure (with constant C=35 if seamless), plus the thickness required to withstand external loads. The areas shall be measured within limits such that (a+b) in Figure 2.1 - Compensation for branch[4]Where the material of a frame, pad or branch has a tensile strength which differs from that of the shell to which it is attached, the compensating area shall be multiplied by the ratio in equation (2.8):

$$\text{Ratio} = \frac{R_y}{R_s} \quad (2.8)$$

Where,

R_c	:	Tensile strength of compensating part
R_s	:	Tensile strength of shell plate

iii) The cross sectional areas of the welding fillets.

c) Compensating plates

In cases where the sum of (i), (ii) and (iii) is less than the area to be compensated a compensating plate shall be welded to the shell, its total cross sectional area being equal to the amount of the deficit and due allowance being made as above when the tensile strength of the material of the plate differs from that of the shell.

Notwithstanding compliance with the requirements of paragraph (b) however, a reinforcing plate shall be fitted around all branches of 100 mm bore diameter and over welded to shell plates having a thickness of 12.5 mm or less.

The compensating plate may be fitted on the inside or outside of the shell plate as most convenient and its diameter shall not exceed twice the longitudinal width of the opening in the shell.

Figure 2.1 - Compensation for branch[4]shows a welded branch to which foregoing requirements apply

Where,

W	:	Width of the opening in the shell, in mm.
T_s	:	Actual thickness of shell, in mm.
T_1	:	Thickness of an equivalent unpierced seamless shell calculated by Equation-1 with C=35, in mm.
T_n	:	Actual thickness of branch, in mm.
T_2	:	Minimum thickness body of branch calculated by (with

C=35 if seamless), in mm.

T_3 : Thickness required to withstand external loads = 3.25mm, unless the loading is known to be such as to require a greater thickness and where there is no external loading T_3– 0.

T_c : Minimum thickness of compensating plate, in mm.

S_1 : Minimum tensile strength of shell plate, in N/mm^2.

S_2 : Minimum tensile strength of branch, in N/mm^2.

S_3 : Minimum tensile strength of compensating plate, in N/mm^2.

W_n : Width of compensating plate in mm measured in the same plate as the shell opening.

Area to be compensated.

$$A = W \times T_1 \tag{2.9}$$

i) Portion of shell available for compensation: -

$$B = 2 \times (75 + T_s) \times (T_s - T_1) \tag{2.10}$$

ii) Portion of branch available for compensation: -

$$C = 2 \times (75 + T_s) \times [T_n - (T_2 + T_3)] \times \frac{S_2}{S_4} \tag{2.11}$$

iii) Portion of welds available for compensation: -

$$D = \text{Total cross sectional area of the internal and external welding fillets in mm}^2 \tag{2.12}$$

If A is greater than (B+C+D), additional compensation is required to make up the difference. In the example shown in Figure 2.1 this is provided by means of a compensating plate, the total compensating area being such that (B+C+D) +Z is not less than A.

Where,

$$Z = 2 \times W \times T_c \times \frac{S_3}{S_1} \tag{2.13}$$

2.5.3 Furnaces [2]

Furnaces of horizontal boilers

(a) The sections of the internal flues shall each be in one plate and shall be bent while cold to circular form and shall be welded longitudinally.

(b) The maximum permissible variation in diameter at any cross-section shall not exceed the thickness of the plate.

Plain furnaces of horizontal boilers

For plain furnaces or furnaces strengthened by Adamson or other joints or stiffeners of sufficient strength and for the semi-cylindrical tops of fireboxes and bottom of combustion chambers where the sides are securely stayed, the working pressure shall not exceed the smaller of the two values obtained from the following formulae:

$$P_w = \frac{10}{\left(D/_{25}\right)} \times \frac{\left(\frac{32\,t}{25} - 1\right)\,2}{\left(\frac{L}{25} + 24\right)} \tag{2.14}$$

$$P_w = \frac{50}{\left(D/_{25}\right)} \times \left[10\,\left(\frac{32\,t}{25} - 1\right) - \frac{L}{25}\right] \times \frac{1}{145} \tag{2.15}$$

Where,

D : The external diameter of the furnace of chamber top or bottom, in mm,

t : The thickness of the furnace plate, in mm,

L : The length of the furnace, in mm,

P_w : Working Pressure, in N/mm^2

Plain Furnaces shall not exceed 3 meters in length except in case of reverse flame boilers which are considered to be inherently flexible.

Flexibility shall be provided in the Furnace by means of corrugations or bowling hoops or stepping of a minimum 150mm in the diameter of Furnace.

If corrugations are used to provide flexibility at least one-third of the Furnace length shall be corrugated.

Plain Furnaces longer than 3 meters are allowed to be used in a boiler when the length between boiler end plates do not exceed 6-5 meters provided.

The relationship between Furnace diameter and permissible heat input is as Figure 2.2 [2]

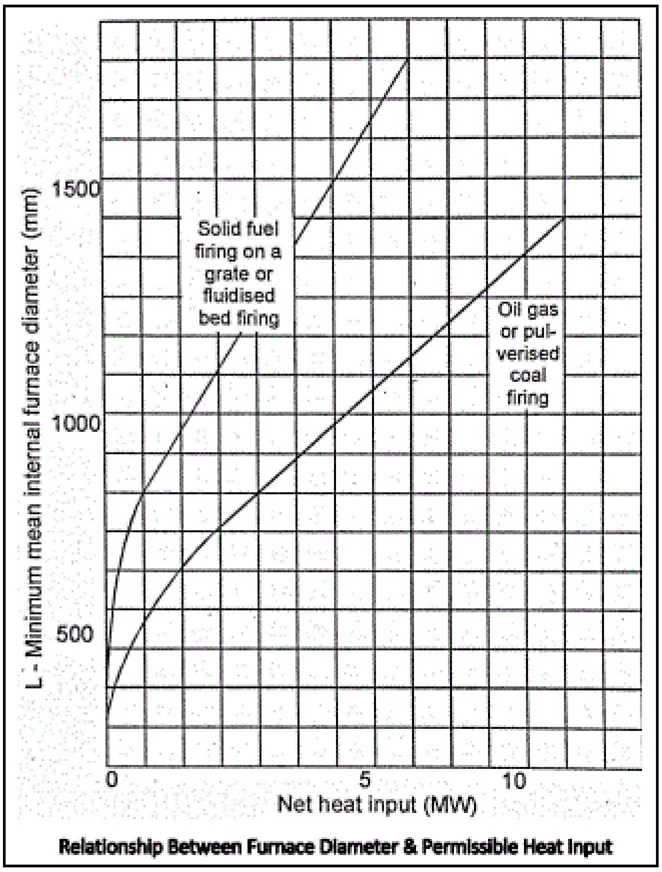


Figure 2.2 - Relationship between furnace diameter and permissible heat input

Furnaces, Furnace Components, Wet-back reversal-chambers and Fireboxes of cylindrical subject to external pressure

The thickness of plain furnaces can be expressed using following equation (2.16)

.

$$e = \max\left\{\left\{\frac{B}{2}\left[1 + \sqrt{1 + \frac{0.12du}{B(1 + 0.3L)}}\right] + C\right\}, \left\{d^{0.6}\left(\frac{LS_2P}{1.73E}\right)^{0.4} + C\right\}\right\} \quad (2.16)$$

Where,

e : Furnace plate thickness (in mm);

B : Pitch of the furnace corrugations (in mm);

d : Mean diameter of furnace (in mm)

u : Percentage out-of-roundness

1.5 For plain furnaces

1.0 For corrugated furnaces;

L : Distance between the centres of two effective points of support

C : Corrosion allowance = 0.75 mm;

S_2 : Factor of safety:

3.0 For Class I and Class II boilers

3.9 For Class III boilers;

E : Young's modulus of elasticity (in kg/cm^2) at the design temperature;

Pitch of the furnace corrugations can be calculated using equation (2.17),

$$B = \frac{PdS_1}{2E_t\left(1 + \frac{d}{15L}\right)} \quad (2.17)$$

Where,

P : Design pressure of the furnace

d : Mean diameter of furnace (in mm)

S_1 : Factor of safety

2.5 For furnaces in Class 1 and Class II boilers

3.5 For furnaces in Class III boilers

2.0 for furnaces and wrapper plates not exposed to flame;

E_t : Specified minimum elevated temperature yield stress or the 0.2% proof stress at the design temperature (in kg/cm^2);

L : Distance between the centres of two effective points of support

Corrugated furnaces of horizontal boilers

The maximum working pressure to be allowed on corrugated furnaces shall be determined by the equation (2.18).

$$P_w = \frac{480}{\left(D/_{25}\right)}\left(\frac{32\,t}{25} - 1\right) \times \frac{1}{145} \qquad (2.18)$$

Where,

P_w : Working pressure in N/mm^2

D : Least external diameter in mm measured at the bottom of the corrugations on the water side in mm,

t : Thickness of the furnace plate in mm measured at the bottom of the corrugation or chamber.

Plain furnaces of vertical boilers

The same formulae as for the plain furnaces of horizontal boilers shall be used, but where the furnaces are tapered the diameter to be taken for calculation purposes shall be the mean of that at the top and of that at the bottom where it meets the substantial support from flange or ring.

Hemispherical furnaces of vertical boilers

When furnaces are hemispherical in form and subjected to pressure on the convex side and are without support from stays of any kind, the maximum working pressure shall be:

$$P_w = \frac{275}{\left({r_o}/{25}\right)}\left(\frac{32\,t}{25} - 1\right) \times \frac{1}{145} \qquad (2.19)$$

Where,

P_w : working pressure in N/mm^2

t : Thickness of the furnace plate in mm measured at the bottom of the corrugation or chamber.

r_o : Outer radius of curvature of the furnace in mm.

2.6 Manufacture [2][3]

2.6.1 Materials of construction

All boiler parts and fittings used in the construction of boilers shall conform to the requirements given in .

Table 2.2[9], [10], [11], [12], [13], [14], [15].

In addition to that, construction of hot water boiler parts such as radiant coil, convective coil, Radiant Coil Header, Convective Coil Header, Expansion Tank shall conform to the requirements given in Table **2.3**[10], [11],[14].

If any other equivalent material is used, prior approval shall be taken from the Inspecting Authority.

The manufacturer shall furnish a certificate issued by the producer of the steel to the effect that steel has been manufactured strictly in accordance with the technical specifications of this standard.

Thickness of the Plates and Grade of steel (maximum tensile strength, elongation etc.)shall be selected to withstand the pressure of five times or more of the maximum working pressure of the boiler. (Safety factor-5 or more).

Table 2.2 - Material Selection for boiler parts and fittings

Boiler Parts And Fittings	Material Requirement
Shell Plate	SLS ASTM A 516 Gr. 70 and/or A36
Furnace	SLS ASTM A 516 Gr. 70
Furnace Plate Ring	SLS ASTM A 516 Gr. 70
RC Wrapper Plate	SLS ASTM A 516 Gr. 70
Front End Plate	SLS ASTM A 516 Gr. 70
Rear End Plate	SLS ASTM A 516 Gr. 70
Furnace End Plate	SLS ASTM A 516 Gr. 70
RC Front End Plate	SLS ASTM A 516 Gr. 70
RC Rear End Plate	SLS ASTM A 516 Gr. 70
Access Plate	SLS ASTM A 516 Gr. 70
Stay Tubes (II Pass)	SLS EN 10216 –1, P 265TR1 SLS EN 10217 –1, P 235TR1
Stay Tubes (III Pass)	SLS EN 10216 –1, P 265TR1 SLS EN 10217 –1, P 235TR1
Gusset	SLS ASTM A 516 Gr. 70
Rest Plate	SLS ASTM A 515 Gr. 70
Stay Rod	SLS ASTM A 105
Stiffener Plate	SLS ASTM A 516 Gr. 70
Manhole Doors	SLS ASTM A 516 Gr. 70 and/or A36
End Plate for Headers	SLS ASTM A 516 Gr. 70
Hand hole Doors for Header	SLS ASTM A 516 Gr. 70 and/or A36
Water Wall Tubes	SLS EN 10216 –1, P 265TR1 SLS EN 10217 –1, P 235TR1
Water Wall Top Header	SLS ASTM A 106 Gr. B
Water Wall Bottom Headers	SLS ASTM A 106 Gr. B
Stop Valve Conn.	SLS ASTM A 106 Gr. B
Safety Valve Conns	SLS EN 10216 –2, P 265GH SLS EN 10217 –2, P 235GH
Air vent Conn.	SLS EN 10216 –2, P 265GH SLS EN 10217 –2, P 235GH
Gauge Glass Conns.	SLS ASTM A 106 Gr. B
Mobrey Conns.	SLS EN 10216 –2, P 265GH SLS EN 10217 –2, P 235GH

Table 2.3 - Material selection for hot water boiler parts and fittings

Boiler Parts And Fittings	**Material Requirement**
Radiant Coil	SLS EN 10217 –1, P 235TR1
Convective Coil	SLS EN 10217 –1, P 235TR1
Radiant Coil Header	SLS ASTMA106 Gr. B SCH 40
Convective Coil Header	SLS ASTM A 106 Gr. B SCH 40
Expansion Tank	SLS ASTMA 516 GR 70

2.6.2 Accessories[4][5]

General

Accessories such as safety valves, blow down valves, shut off valves, water level indicator and pressure gages etc. should conform to the respective national standards of the country of manufacture.

All the valves and fittings shall be manufactured by an accredited manufacturer in accordance with the relevant boiler/pressure vessel standard.

The boiler manufacturer shall obtain a certificate from the supplier/maker for each fitting/valve which are to be fitted to the boiler. The certificate of the maker shall include the following information:

01. Test certificate number and date
02. Maker's name, address, e-mail etc.
03. Maker's brand name
04. Name of the fitting/part
05. Allowable operating pressure/ pressure range
06. Hydraulic test pressure and date
07. Critical dimensions
08. Body material
09. Assembly drawing number
10. Limiting parameters of media for which valve/fitting can be used
    a)Intended working temperature
    b)Permissible working pressure;

11. Chemical composition and physical test report on ultimate tensile strength, elongation and bend test etc. and
12. S: Number of the Fitting /Valve

The certificate should be signed by manufacturer's representative and any of their cognized third party inspection authority of the country of origin.

In addition to those above, for hot water boilers following requirements shall be applied.

Valves –Only cast steel global valves shall be used and only flange connections shall be used with valves.

Raised face flanges shall be used in hot water piping.

Threaded connection shall not be used in the hot water piping. Use only welded connection and Stainless Steel Needle valves.

One or more drain valves shall be used at the lowest points in the installation.

A 60 mesh strainer shall be used before the Hot Water circulation in the return line.

Safety valves

General

Safety valves, ordinary, high lift and full lift, shall be so constructed that breakage of any part will not obstruct the free and full discharge of steam from the boiler.

Ordinary Lift Safety Valve – A safety valve in which the valve head lifts automatically a distance of at least D/24 with an over-pressure not exceeding 10% of the set pressure. There shall not be any mechanical stop which would prevent the valve head from being lifted a distance of at least D/8. D is the minimum bore of the Body seat.

High Lift Safety Valve – A safety valve in which the valve head lifts automatically a distance of at least D/12 with an over pressure not exceeding 10% of the set pressure. There shall not be any mechanical stop which would prevent the valve head from being lifted a distance of at least D/8. D is the minimum bore of the body seat.

Full Lift Safety Valve – A safety valve in which the valve head lifts automatically a distance such that the area of discharge which limits the flow through the valve is between 100% and 80% of the minimum area at any section at or below the body seat. This lift is achieved by a rapid opening within an over-pressure not exceeding 5% of the set pressure.

Minimum Aggregate Area

Discharged Capacity of Safety Valves:

i) Saturated Steam

The rated discharge capacity of a safety valve which discharges saturated steam shall be calculated using the equation(2.20):

$$E = CAP \tag{2.20}$$

Where,

E : Rated discharged capacity of saturated steam (kg/h)

C : Constant

A : Area (mm^2), and

P : Highest pressure of any safety valve mounted on the boiler (bar absolute),

For the ordinary lift and high lift safety valve, A is the area of the minimum bore of the body seat. For full lift safety valves, A is the area of discharge described in clause I and its valve can only be obtained from the safety valve manufacturers. C is a constant taken from the Table 2.4, appropriate to the type of the valve.

Table 2.4 - Value of constant 'C'

Type of valve	**Value of the constant 'C'**
Ordinary lift	0.05
High lift	0.10
Full lift	0.24

ii) Superheated Steam

The rated discharge capacity of a safety valve that discharges superheated steam shall be calculated using the following equation.

$$Es = \frac{E}{{}^{1}/_{1000}\sqrt{1 + 2{,}7Ts}} \tag{2.21}$$

Where,

E_s : Rated discharge capacity of superheated steam (kg/h)

E : Rated discharge capacity of saturated steam calculated using Equation 78 (kg/h),

T_s : Degree of superheat (°C)

The above equation may be used to determine the rated discharge capacity of safety valves at super-critical steam pressure. In these cases the saturation temperature of the steam shall be taken as 375 ^{0}C.

The total peak load evaporation of a boiler shall be calculated on the basis of evaporation not less than 30 kg/hr/m^2 of heating surface (exclusive of super heater and non-steaming economizer). In the case of Waste Heat Boilers, however, when the evaporation per square metre of the heating surface is certified by the manufacturers to be less than 30 kg. The minimum number of safety valves required may be calculated on the basis of the actual maximum evaporation of the boiler.

Over-pressure of safety valves

The safety valves shall be so designed that they attain rated discharge capacity with the over pressure not greater than that given in provided that the safety valves which have a large area less than 80 per cent of the flow area, the over-pressure at which the design lift is attained shall not exceed 10 per cent of the set pressure. For safety valves having discharge area 80 per cent or more of the flow area, the over-pressure at which the design lift is attained shall not exceed 5% per cent of the set pressure.

Pressure drop

The safety valves shall be reset at a pressure at least 2.5% below, but not more than 5% below safety valve set pressure. The 5% limit is increased to 10% for valves having a body seat bore less than 32mm and or having a set pressure of 2 bar gauge or less.

Mounting of safety valves

Safety valves shall be mounted, without any intervening valve, on pads or branches used for no other purpose. The axis of the valve shall be vertical. The cross-sectional area of the bore of each pad or branch shall be at least equal to the area of the bore at the inlet of the safety valve, or where two or more safety valves are mounted on the same pad or branch, at least equal to the sum of the areas of the inlet bores of all the safety valves.

Branches shall be as short as possible so as not to impair the proper action of the safety valves or impose any undue stress on the branches at their point of attachment to the boiler. Nothing shall obstruct free flow to the safety valve. Branches, particularly when full lift safety valves are mounted on them, should be reduced at the inlet. The inlet and outlet flanges shall be drilled in accordance with the approximate table in Appendix E for the diameters of flanges adopted.

The Manufacture must conform to a recognized standard. The Safety valve shall be of direct spring-loaded pop type, properly marked as to pressure and capacity and equipped with a testing lever. The pressure setting must be just above the maximum allowable pressure. The capacity of the safety valve shall be at least equal to the maximum steam generating capacity of the boiler. The following information shall be marked legibly and indelibly on the valve body or name plate.

01. Manufacturer's name or trademark
02. Manufacturer's type or design number
03. Size (mm/in)
04. Seat diameter (mm or inches m/in)
05. Pressure at which valve is set to blow,
06. Blow back /Blow down
07. Discharge capacity

The range of adjustment permitted with a spring is 10 percent of its rated setting. This rule is for safety valves set at up to 17.5 bar (1.75 N/mm^2). For higher pressures, the allowable range of adjustment is 5 percent of the spring rating. Should the setting be changed to a greater deviation, a new spring and nameplate should be installed by the manufacturer.

Steam stop valve

The stop valve attached to the boiler shall be located as close as practicable to the shell or drum in case of water tube boiler. The attachment of steam stop valve to the boiler can be made by bolted flanges or butt welded joints. Such butt welded joints shall be stress relieved, where necessary.

A vertical stand pipe not exceeding 5 times the diameter in height is permitted between the stop valve and the boiler. Such stand pipes shall be of strong construction of steel.

Blow down valve and fittings

Each boiler shall be fitted with a suitable blow down valve as close as practicable to the lowest water space of the boiler. Globe valves shall not be permitted for this purpose.

Blow down valves and fittings shall be designed for at least 25% higher pressure than the maximum allowable pressure on the boiler. Cast iron fittings shall not be used.

Water gauges

Every steam boiler shall have at least one water level gauge.

Water gauges shall be so placed as to be easily seen and reached by the boiler operator.

The lowest visible part of the glass of the water gauge and lower test cock shall be fixed at safe working level.

With fire tube boilers, the lowest safe water level shall be minimum 25 mm from the top of the top row of tubes.

With vertical boilers lowest water level shall not be less than 50 mm above highest point of the firebox roof plate. Minimum visible length of the gauge glasses shall be 200 mm.

With water tube boilers safe water level shall be 150mm above the bottom of the boiler drum.

Low water level shall be marked visibly on the glass of the water level gauge.

A drain cock or valve with a suitable discharge pipe shall be fitted to each water level gauge.

Substantial protection for the gauge glass shall be provided.

Tubular water gauge glasses shall not be less than 12 mm and not more than 18 mm outside diameter.

The gauge cocks when open shall have their handles in a vertical direction and each handle at its junction with the plug shall be visibly marked with a deep line to indicate the direction of the passage way through plug.

Pressure gauges

i) Pressure gauge shall be of approved type

ii) The pressure gauge range shall, as far as practicable, be twice as the maximum allowable pressure of the boiler.

iii) The scale on the dial shall be clearly and permanently marked.

iv) The dial of the pressure gauges shall not be less than 150 mm in diameter.

v) The pressure gauge shall carry a calibration certificate by the manufacturer.

Connections

All pressure gauges shall be fitted with a siphon pipe and a cock or valve integral with, or adjacent to, the gauge in such manner that the gauge may be shut off and removed whilst the boiler is under steam.

Gauge cocks

The handles of the gauge cocks shall be parallel to the pipes in which they are located when the cocks are open and marks shall be cut on the shank of the cock indicating open position.

Test connections–master(pressure) gauge attachment

Every boiler shall be fitted with a valve or cock carrying in a vertical position a receiving screw for attachment of the Competent Person's pressure gauge. The receiving socket shall be tapped for M/20x1.5 metric threads and shall be fitted with an easily removable cap.

Fusible plugs

a) General

i) Fusible plugs shall be of sufficient height and fitted in such a position as to give early protection to all parts of the boiler liable to damage by the direct application of furnace heat in the event of running out of water.

ii) On Boilers having wet back reversing chamber, a minimum of two fusible plugs shall be fitted; one on the crown of the reversing chamber and the other on one of the tube plates. On boilers not having wet back reversing chamber, at least one fusible plug shall be provided on the front end tube plate. The plug shall be fitted in such a way that in the event of fusion of the plug, the pressure inside the boiler shall releasewater throughthe plug.

b) Type

Fusible plugs shall consist of an outer body with a central conical passage the smallest part to be not greater than 12.5mm for plugs suitable for pressure up to 7 bar (0.7 N/mm[2)] and not greater than 9.5 mm for plugs for pressures exceeding 7 bar (0.7 N/mm[2)]. The passage shall be closed by a plug secured by an annular lining of fusible alloy so that the plug may drop clear if the lining melts. The portion of the body carrying the fusible metal should preferably be detachable from the base to allow of easy replacement without removing the whole fitting from the boiler.

c) Material

The non-fusible portions of the plug shall be of bronze except where the nature of the boiler water precludes the use of a non-ferrous material. The fusible metal shall be an alloy melting readily when the temperature exceeds 65°C of the saturated steam temperature at the maximum permissible working pressure of the boiler.

d) Attachment to boiler

Wherever practicable fusible plugs shall be screwed into the boiler plates from the water side. The screwed portion shall have threads of metric form of M16×2.

Draft

The Forced Draft fan which supplies air for combustion of fuel and draft and Induced Draft fan which pulls the flue gas out of the boiler into a stack shall be centrifugal / axial types. They shall be dynamically balanced.

In balanced Draft system using both Forced Draft and Induced Draft shall be properly balanced in the amount of air and flue gas handled, so that the furnace pressure is just above atmospheric. Interlocks shall be provided between fans in order to avoid implosions and combustion problems. Prior to installation, interlock design shall be forwarded to inspecting authority for approval.

2.6.3 Boiler safety control system [4]

The following boiler safety control systems shall be provided.

i) Two low water fuel cut offs (Oil / Gas fired boilers) with manual reset for low water and extra low water levels. During low water fuel cut offs an alarm shall be activated.

ii) In case of bio-mass boilers ID / FD fans shall get cut-off when water level goes below safe level. Approval for the design of low water control system shall be obtained from the inspecting authority prior to installation.

iii) One pressure sensing device shall be fitted to control the boiler pressure within required range. At the higher set pressure which shall be less than the maximum permissible working pressure fuel (oil/gas) shall get cut off and at lower set pressure the boiler shall get started. An additional pressure sensing switch may be provided for controlling higher and low fire flame in oil / gas fired boilers.

In bio-mass fired boilers one pressure sensing controller shall be provided in order to cut off ID / FD fans at the desired set pressure. The boiler shall get started when the pressure drops below the lower set pressure. In any case the operating pressure range should not exceed the maximum permissible working pressure.

In addition to those mentioned above, in case of hot water boilers following devices shall be used.

01. Hot Water temperature control.

02. A temperature indicator and controller to cut off ID/FD fan or burner at

pre-set temperature and restart at differential temperature to maintain the systems temperature.

03. A temperature controller for cutting off ID/FD fan or burner and activate an alarm when stack (flue gas) temperature exceed the pre-set temperature.
04. A flow controller to cut off ID/FD fan or burner and activate an alarm in the event of low flow in the system
05. A visual level indicator and float actuated level switch attached to the expansion vessel
06. An interlock to cut off ID/FD fan or burner in case of tripping of Hot Water Pump.
07. A mechanism to drive the hot water pump in case of power failure.

Automatic ignition controls

Purging of furnace shall be thorough on any firing (oil / gas) or restart in order to clear the furnace passages of any unconsumed fuel and thus prevent a fireside explosion. The design of automatic ignition control shall be subjected to prior approval from the inspecting authority

Flame failure safety controls

Flame sensing devise shall be installed to ensure the fuel cut-off in the event of flame failure during operations. For oil / gas burners only UV type photocells or any equivalent flame sensing device shall be used.

Front door interlock (oil / gas fired boilers) for horizontal fire tube boilers

This interlock shall ensure that no firing will take place unless the door is fully closed.

2.6.4 Rolling margin [2]

No plate or rolled section shall be under the specified thickness at any part, not more than 5 per cent over the calculated weight, except that in the case of thin plates and wide plates the weight tolerances shall be as set out in the Table 2.5 below:

Table 2.5 - Schedule of percentage of rolling weight tolerances for boiler plates

Thickness mm	**Width meters**								
	<1.2	1.2<1.5	1.5<1.8	1.8<2.1	2.1<2.4	2.4<2.7	2.7< 3.0	3.0<3.3	3.3<
	Percentage of Rolling weight tolerances								
6 < 8	5	5	5	7	9	12	..	..	..
8 < 9.5	5	5	5	6	7.5	10	11	12	..
9.5 < 11	5	5	5	6	6	8	9	11	15
11 < 13	5	5	5	5	6	7.5	8	9	12
13 < 16	5	5	5	5	6	6	7.5	9	10
16 < 19	5	5	5	5	5	5	7	8	9
19 < 25	5	5	5	5	5	5	6	7	8
25 < 50	5	5	5	5	5	5	5	9	7

2.6.5 Construction and workmanship

Welding and quality assurance in welding

- This section shall cover the essential requirements to be met with in order to meet with the necessary quality requirements of welding work during manufacture of boilers.
- All welding work shall be carried out by qualified and certified welders using approved welding procedures.
- All welding shall be inspected and approved by the attending inspecting engineer prior to hydraulic testing of the boiler.
- The manufacturer shall submit the following records/documents duly completed to the inspector prior to the commencement of the construction work.
    - The welding procedure specification (WPS) applicable to the particular joint.
    - The procedure qualification record (PQR) for each WPS.
    - Welder qualification Test results.

- The inspector shall use the guidelines stipulated in this standard and if necessary, any other internationally accepted standard, for approving the aforesaid records/documents.

- The welding procedure specification shall be in the format recommended by any of the IACS (International Association of Classification Societies) but shall include the following essential information:
  a) The joint preparation/design.
  b) The welding process.
  c) The filler metal (Welding consumable/electrodes). The ultimate tensile strength (UTS) of the filler metalshall not be lower than that of the parent metal.
  d) Type, size and AWS classification of filler metal for each welding run.
  e) Voltage, current and speed of traverse of the filler metal/electrode for each welding run.
  f) Pre-Heat and Post Weld Heat Treatment (PWHT) requirement for the particular weld.

- For butt-welds WPS shall be approved by conducting the following tests on a sample test piece welded in accordance with the same WPS.
  a) One radiographic test.
  b) Two tensile tests.
  c) Two face bends test.
  d) Two root bend tests.
  e) Fillet welds shall be tested and approved by the inspector by conducting the following tests:
    i) Visual inspection.
    ii) Macro examination of a cross section of the weld.
    iii) Fracture test on one sample weld.
- Procedure qualification tests and welder qualification tests stipulated in Section 6 above shall be witnessed and certified by the inspector.

- Once a welding procedure is approved the same can be adopted in different applications subjected to the limitations given in IACS specifications.

- Welder qualification too can be used for different applications subjected to the limitations given in IACS specifications.

- The design should indicate clearly the joint details and also the corresponding WPS applicable for every joint.

- Inspection upon completion of welding.: The following essential inspection shall be carried out immediately after the completion of welding work :
  a) Hundred percent (100%) visual inspection of all welds.
  b) Hundred per cent Radiographic inspection on longitudinal butt welds on the boiler shell.
  c) Ten per cent radiographic inspection on circumferential butt welds on the boiler shell.
  d) Magnetic particle inspection (MPI) on boiler tube to end plate connection.

- Stress relieving/ Post welded heat treatment

  Stress Relieving or Post Weld Heat Treatment is the uniform heating of a complete structure or parts thereof (Welded Joint) to a temperature just below the critical metal range. The purpose of stress relieving is to relieve the major residual stress that may exist in a welded joint from the heat effects caused by the welding process.

  All boilers shall be stress-relieved by heat-treatment after completion of all welding and before hydraulically test if any plate is 20 mm thick or greater or carbon content of the steel exceeds 0.25% of the material used in the construction of boiler.

  For carbon steel a stress relieving heat-treatment shall be performed by heating part to at least 600±20 °C when required by the characteristics of the material, different temperatures may be necessary to obtain proper stress-relieving. The part to be stress-relieved shall be brought slowly up to the specific temperature and held at that temperature for a period proportionate on the basis of at least 2½ minutes per 37 mm of the maximum thickness of part (approximately one hour per 25 mm of thickness) and shall be left to cool in the furnace to a temperature that does not exceed 400^{o}C for the parts with a thickness greater than 20 mm. After withdrawal from a furnace the part shall be allowed to cool in a still atmosphere. A temperature time diagram of the stress-relieving process shall be provided for a welded shell or drum and a similar diagram for other welded pressure parts when the Inspecting Authority requires it.

Inspection during construction

All boilers during construction shall be under the supervision of an inspecting authority and shall be inspected at all stages of construction prescribed in accordance with the format recommended by any of the IACS but shall include the essential information as described in **Welding and quality assurance in welding.**
Welders engaged at site welding of any of the parts subjected to high pressure parts shall possess and produce the Welders Performance Qualification Certificate issued by a competent authority to the satisfaction of the inspecting authority.
Certificates to be furnished with in advance of or along with an application for registration for manufacturing a boiler with the inspecting authority.

The following certificates and drawings or specifications shall be furnished to the inspecting authority, namely:

i. A certificate in Form –2: From the inspecting authority certifying that the materials has been inspected and the boiler was built under their supervision. Together with such certificate the inspecting authority may furnish a Memorandum of Inspection book in Form-1 prepared in the manner prescribed by this standard in respect of the inspection of the boiler during construction and hydraulic test applied on completion.
ii. A certificate in Form-3 of manufacture and test signed by the maker of or by a responsible representative of the maker of the boiler containing a description of the boiler, its principle dimensions, particulars of any deviation from ordinary practice in making the shell such as solid rolling or welding, the hydraulic test to which the boiler was subjected, the intended working pressure, the area of heating surface, the maximum continuous evaporative capacity, the year and the place of make and the works number of the boiler.
iii. A certification in Form- 4 from the steel maker and a certificate from

the maker of the plates, bars shall show charge numbers, the plate or bar numbers and the number and dimensions of the various plates etc. Tested, their chemical analysis, their ultimate tensile braking strength in tons per square inch of section, the percentage of elongation and the length on which measured the number, kind and result of bend or other tests made and the date of tests.

2.7 Inspection and testing [2]

2.7.1 Inspection and testing of boiler during manufacture

General

The Inspecting Authority shall have access to the work place of the manufacturer as and when required and shall inspect the boiler during the manufacture of the Boiler at least at the following stages and reject any part that does not comply with the requirements of this standard. If deemed necessary, the Inspecting Authority shall examine stages specified in the standard.

The manufacturer shall give a notice at least 4 working before the Inspecting Authority/Inspecting Engineer before reaching each stage. These Stages may be combined to suit convenience of the Inspecting Authority.

Before undertaking any of the stage inspections, the Inspecting Engineer shall satisfy himself that the testing equipment/instrument used by the manufacturer has been properly calibrated.

Inspection of material during manufacture

Each Boiler shall be inspected during manufacture by an Inspecting Engineer, nominated by the Inspecting Authority. Sufficient inspections shall be made to ensure that the materials, fittings, construction and testing conform to the requirements of this standard.

Inspection of materials

The following inspection requirements shall be mandatory

01. When the plates have been received in the workshop of the manufacturer and are ready for checking of identification numbers with the steel maker's mill certificates for identification and also for stamping of test pieces repre-

sentative of the welded seams for future identification before being cut from the parent plate in the case of fusion welded boilers.

02. When the tubes have been received in the workshop of the manufacturer and are ready for checking of identification numbers with the Tube manufacturer's certificates.

03. Check the identification markings on the plate with those recorded on the plate makers' certificates.

04. Check the reported result of the mechanical and chemical properties on the plate makers' certificates against requirements of this standard.

05. Witness the marking of the test plates for identification before they are cut from the parent plate or plates.

Shell type boilers

01. When the shell and end plates have been formed with plate edges prepared for welding and test plates are attached.

02. When the welding of main cylindrical shell is completed and ready to be checked for circularity.

03. To examine radiographs and/or reports of other non-destructive testing.

04. When openings have been prepared and stand pipes and similar connections including end plates have been tack welded in position and subsequently on completion.

05. When welding of drum or shell is completed and to check the records of heat treatments

06. When weld test specimens have been prepared from the test plate, previously selected to witness the required testing.

07. Complete hydraulic pressure test, followed by external and internal examination and stamping.

Valves and Mountings

When pre-casting materials are ready for examination and selection for tests

Non Destructive Testing(NDT) Inspection

All NDT inspectors shall possess minimum of ISO Level -2 qualification in their respective fields.

Hydraulic pressure test

A hydraulic pressure test at 150 percent of the design pressure shall be conducted non-destructive. During this test visual inspections are made of welds, joints, connections for leakage while any drop in pressure observed will indicate hidden leaks.

a) The test shall be witnessed by the Inspecting Engineer.
b) The test pressure shall be maintained for a period not less than 30 minutes.

It is important in the interest of safety that the boiler be properly vented, so as to prevent the formation of air pockets, before the test pressure as applied.

NOTES:

01. It is recommended that the temperature of the water should not be less than 21 ^{0}C during the hydraulic test.
02. It is further recommended that before the boiler is approached for close examination, the pressure shall be reduced to not less than 1.1 times the design pressure and not more than 0.9 times the hydraulic test pressure.
03. On completion of hydraulic test, release of pressure shall be gradual.
04. Deflection of different pressure parts shall be examined carefully and there shall be no any permanent set after release of pressure.

If any repairs are found to be necessary during or subsequent to the hydraulic pressure test, the boiler shall again be subjected to the pressure test specified above after completion of the repairs and after any heat treatment.

NOTE:

Observations and remarks of inspecting officer / inspecting authority should be recorded for filing with maker’s papers.

Inspection of boiler plates

The Boiler Manufacturer shall obtain following test certificates from the manufacturer of plates: -

01. Chemical analysis
02. Tensile Test
03. Bend Test

04. Elongation Test

05. Any other relevant Tests

The Boiler plates shall be inspected by the Inspection Authority before manufacturing the Boiler. If the Inspection Authority is not satisfied with the certificates the manufacturer shall instruct to check the material composition and further testing if necessary in an authorized Laboratory.

The acceptance of the boiler plates shall be the responsibility of the inspecting engineer.

2.8 Marking [4][5]

2.8.1 General

Each boiler and separate unit shall be permanently and legibly marked to show its identity and origin. This marking may be made above the manhole of the main steam and water drum, or on a plate permanently attached thereto, or where this is not applicable. (E.g. for once-through boilers, on a plate permanently attached to a principal pressure part or on the steel structure of the boiler).

Each pressure part which must be identifiable during manufacture, e.g. in order to implement the recording procedure required by this Standard shall be temporarily marked. Temporary marks may be made with metal stamps having radius edges provided that these marks lightly and before final heat treatment. Temporary marks shall be subject to visual examination by the fabrication inspector which may require them to be removed by grinding after inspection.

2.8.2 Marking required

The marking shall show the following particulars

The name and address of the manufacturer;

The manufacturer’s serial number;

Capacity from and at 100 º C;

Maximum allowable working pressure;

The mark of the inspector and the model;

The design code/standard;

The date of hydrostatic test and the test pressure in N/mm^2; and

The year of manufacture.

3 BOILER PRESSURE PART MATERIALS

Selection of pressure vessel material is one of the most important and crucial stages of the process of boiler manufacture. Even though the suitable materials (steel sheets) are available in the market, selection of right thickness of sheets is very crucial.

Therefore, as discussed in ‘Literature Review’ considering **A36** stee las the material available in the market, steel sheets of grade **A36** will be used for comparison with respect to the material specified in the standard, SA 515/516 Gr.70. A comparison of A36 and IS 2062 will show how the above statement is justifiable.

Table 3.1 - Equivalents of Carbon Steel Qualities [12]

COMPARISION / EQUIVALENT CHHART										
STRUCTUITRAL STEEL PLATES		**CHEMICAL PROPERTIES**					**PHYSICAL PROPERTIES**			
		C	Mn	S	P	Si	Y S (MPa) (Min)	UTS (MPa) (Min)	El(%)	IMPACT (Min)
INDIA	IS 2060 GR.A	0.23	1.50	0.050	0.050	0.40	t<20mm 250 t=20-40mm 240 t>40mm- 230	410	23	N.A
U.S.A	A36	0.25	0.80-1.20	0.050	0.050	0.40	250	400-550	18	27J at 0^0C
EURO,	EN 10025 S235	0.17	1.40	0.035	0.035	-	235	340-470	23	27J at 20^0C
	EN 10025 S275	0.18	1.50	0.035	0.035	-	275	410-560	21	27J at 20^0C
CHINA	Q 235	0.14-0.22	0.30-0.65	0.050	0.045	0.03	t<16mm 235 t= 16-40mm 225 t>40mm 215	375-500	t<16mm 26 t= 16-40mm 25 t>40mm 24	27J at 20^0C

This comparison compares data on Chemical Properties and Physical Properties of the two selected materials and this can be further extended up to the decisions to be made so as to derive the assistance of international and/or national standards and/or codes. The table of ‘Equivalents of Carbon Steel Qualities’ is mentioned above.

The above Table 3.1shows that **A 36**[10] is equivalent to **IS 2062 Grade A** [11]. Even though initially the said equivalence is essential, if the material is to be selected for the purpose, some other important parameters shall also be considered, mainly such as thickness of the sheet. In view of such calculations with regard to basic design, assistance has to be derived from an existing standard or code.

3.1 Design calculation(sample)

Taken in a nut shell, since most of the boilers are being imported from India, and the industry has been well established in India, attention has to be paid inevitably to the Indian Boiler Regulations or commonly recognized as **IBR**. Therefore, a sample calculation would be as discussed below, only for the shell, tube plate, man holes, hand holes and doors.

3.1.1 Design of pressure parts with a material specified in the standard

Shell design[4]

Considering **SA 515/516 Gr 70** as the material specified in the standard for the shell,

Minimum tensile strength: 485 N//mm^2

Allowable stress R can be calculated using Equation (2.1

$$R = \frac{485}{2.7} \text{ or } \frac{260}{1.5} = 179.63 \text{ or } 173.33$$

Now, considering the lower value for shell under internal pressure, the working pressure$P_w$from equation (2.2),

$$P_w = \frac{2RE(t-1)}{d+t-1} \tag{3.1}$$

Where,

t : Thickness of Shell, in 10.00 mm

d : Inside Diameter of Shell, 1950 mm

R : Minimum Tensile Stress for Plate, in 173.33 N/mm^2

E : Weld Factor = 1 (if 100% X-Rayed)

$$P_w = \frac{2 \times 173.33 \times 1 \times (10 - 1)}{1950 + 10 - 1} = 1.593 N/mm^2$$

Required plate thickness can be obtained from equation(3.2[2]

$$t = (d \times P)/(2RE - P) + 1 \quad (3.2)$$

Where,

P : Design pressure

here P = 10.9 kg/cm^2= 1.069 N/mm^2

Required plate thickness	=	(1950 × 1.069)/ (2 × 173.33 × 1 – 1.069) + 1
	=	7.03 mm;
Provided plate thickness	=	10.00 mm;
Calculated pressure	=	1.593 N/mm^2
Design pressure	=	1.069 N/mm^2

Since the design pressure is less than the calculated working pressure, provided thickness is adequate.

However, considering the ASME BPV 2010 PG 27.4, working pressure P_w is given by equation (3.3):

$$t = \frac{PR}{(SE - 0.6 \times P)} \quad (3.3)$$

where,

t : Minimum required thickness (in.)

P : Design pressure (psi)

R : Inside radius (in.)

S : Allowable stress (psi)

E : Weld joint efficiency factor, determined by joint location and degree of examination

Therefore,

$$t = \frac{(1.069 \times 145.0377)(975/25.4)}{(16600 \times 1 - 0.6 \times 1.069 \times 145.0377)} = 0.3605 \text{ in} = 9.1579 \text{ mm}$$

But since the provided thickness (10 mm) is not adequate, a sheet which is thicker than that is needed.

Tube plate design using the same material as above in a
Using equation (2.4)

$$t = \frac{400L \times P_w}{RJ} + 2$$

J = 100(89.0 – 43.5) /89.0

= 51.12

P_w = 1.593 N/mm^2
R = 260 N/mm^2

L = (Diameter of the largest circle provided /2) – (Outside diameter of tubes/2)

= (352/2) – (63.5/2) = 144.25

Therefore,

$$t = \frac{400 \times 144.25 \times 1.593}{260 \times 51.12} + 2 = 8.195 \text{ mm}$$

Since the design thickness of the tube plate is less than the thickness of the plate provided, design is safe.

Thickness of Manholes and Hand holes door using the same material.

The minimum calculated thickness of the door of the flat plate construction (i.e. Unstiffened made from one plate) shall be not less than that determined by the equation(2.6) for circular door and equation (2.7) for elliptical door: -

For a circular Door: [2]

$$t = \sqrt{\frac{0.35P_w \times d^2 + W}{f}}$$

For and Elliptical Door: [2]

$$t = \sqrt{\frac{0.35P_w\left(2 - \frac{a}{b}\right) \times a^2 + W}{f}}$$

NOTE:

Design stress of value of 50 N/mm^2 may be used for carbon steel bolts for design temperature not exceeding 300 °C.

Considering an elliptical door design,

a	=	320 mm
b	=	420 mm
Effective stud diameter	=	31.8 mm

Therefore,

$$t = \sqrt{\frac{0.35 \times 1.593 \times \left(2 - \frac{320}{420}\right) \times 320^2 + (50 \times \pi \times 15.9^2)}{146.67}} = 27.43\ \text{mm}$$

Hence the provided thickness 28.00 mm which is more than that of required i.e. 27.43 mm, manhole door design is safe.

In general, the above calculation shows that the relevant listed materials in .

Table **2.2** comply with the laid down requirements. In addition to this any non-pressure part can be designed in accordance with general engineering requirements so that any pressure part shall not be affected thereof.

3.1.2 Design of pressure parts with a material specified in the standard

Shell design

As discussed in Clause **2.5.1**, considering **A36 steel** as the material available in the market, do the same calculation similarly.

Calculation:

Minimum tensile strength: 400 N//mm^2

Allowable stress, R as per the standard requirements:

$$\mathrm{R} = \frac{400}{2.7}\,\mathrm{or}\,\frac{220}{1.5} = 146.67\ \mathrm{or}\ 148.15$$

Now, considering the lower value for shell under internal pressure, the working pressure,

$$\mathrm{P_w} = \frac{2\mathrm{RE}(\mathrm{t}-1)}{\mathrm{d}+\mathrm{t}-1}$$

$$\mathrm{P_w} = \frac{2 \times 146.67 \times 1 \times (10-1)}{1950+10-1} = 1.348\ \mathrm{N/mm^2}$$

Required plate thickness,

$$\mathrm{t} = (\mathrm{d}\ \times\ \mathrm{P})/(2\mathrm{RE} -\ \mathrm{P}) + 1$$

Where,

P : Design pressure

here P = 10.9 kg/cm^2= 1.069 N/mm^2

Required plate thickness = (1950 × 1.069)/ (2 × 146.67 × 1 – 1.069) + 1

= 8.13 mm;

Provided plate thickness = 10.00 mm;

Calculated pressure = 1.348 N/mm^2

Design pressure = 1.069 N/mm^2

Since the design pressure is less than the calculated working pressure, provided thickness is adequate.

Table3.2 - Comparison between plate thickness using local material and IBR material

Grade of Steel Plate	SA 515/516 Gr 70	A 36
Required plate thickness(mm)	7.03	8.13

Tube plate design using the same material [4]

Where boilers have a nest or nests of horizontal tubes, and there is a direct tension on the tube plates due to the direct load on the boiler ends or to tube plates acting as ties across the shell:

i) Each alternative tube in the outer vertical row of tubes shall be a stay tube.
ii) The thickness of tube plates and the spacing of the tubes shall be such that the effective area of the metal taking the load is sufficient to keep the stress within that allowed on the shell plate, as determined by Using equation (2.4).

$$t = \frac{400L \times P_w}{RJ} + 2$$

where J is given by equation (2.5)

$$J = \frac{100 \times (P - D)}{P}$$

Now,

J = 100(89.0 – 43.5) /89.0

= 51.12

P_w = 1.347 N/mm^2
R = 220 N/mm^2

L = (Diameter of the largest circle provided /2) – (Outside diameter of tubes/2)

= (352/2) – (63.5/2)

= 144.25

Therefore,

$$t = \frac{400 \times 144.25 \times 1.347}{220 \times 51.12} + 2 = 8.910 \text{ mm}$$

Since the design thickness of the tube plate is less than the thickness of the plate provided, design is safe.

Table 3.3 -Comparison between plate thickness using local material and IBR material

Grade of Steel Plate	SA 515/516 Gr 70	A 36
Required plate thickness(mm)	8.915	8.910

Thickness of Manholes & Hand holes door:

The minimum calculated thickness of the door of the flat plate construction (i.e. Unstiffened made from one plate) shall be not less than that determined by equation (2.6) for circular door and equation (2.7) for elliptical door: -

For a circular Door: [4]

$$t = \sqrt{\frac{0.35P_w \times d^2 + W}{f}}$$

For and Elliptical Door:

$$t = \sqrt{\frac{0.35P_w\left(2-\frac{a}{b}\right)\times a^2+W}{f}}$$

NOTE:

Design stress of value of 50 N/mm^2 may be used for carbon steel bolts for design temperature not exceeding 300 °C.

Considering an elliptical door design,

a	=	320 mm
b	=	420 mm

Effective stud diameter = 31.8 mm

Therefore,

$$t = \sqrt{\frac{0.35\times 1.347\times\left(2-\frac{320}{420}\right)\times 320^2+(50\times\pi\times 15.9^2)}{146.67}} = 26.04\text{ mm}$$

Hence the provided thickness 28.00 mm which is more than that of required i.e. 26.04 mm, manhole door design is safe.

In general, this calculation can be extended for the boiler as a whole, using the formulae mentioned under Chapter 2 and it can be shown that the material selected i. e. A 36, insearch of the industrial survey comply with the laid down requirements of the adopted standard.

In addition to this any non-pressure part can be designed in accordance with general engineering requirements using the same material (A 36) or any other suitable material so that any pressure part shall not be affected thereof.

Table 3.4 - Comparison between plate thickness using local material and IBR material

Grade of Steel Plate	SA 515/516 Gr 70	A 36
Required plate thickness(mm)	27.43	26.04

Therefore, solution for the lack of quality materials or they are expensive and for not following pressure vessel design calculations, this approach can be adopted as a remedy.

4. PRESSURE VESSEL WELDING

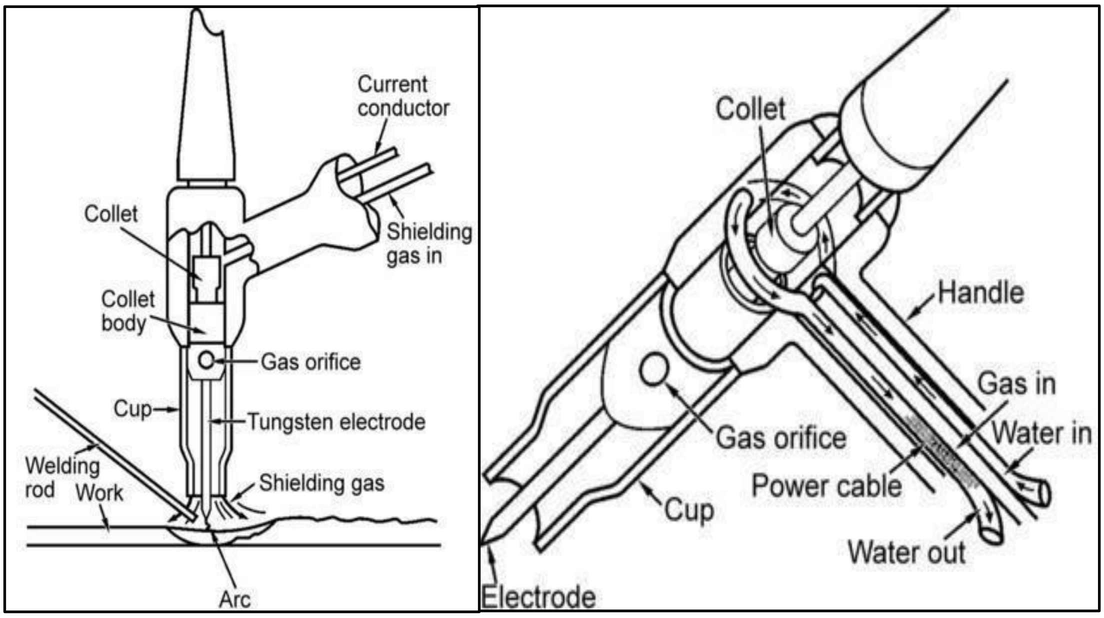
3.2 4.1 Introduction

This welding process must be performed carefully and precisely as well so that there is no any room for any failure to take place during commissioning or thereafter because such a failure may cause multiple deaths as discussed in Chapter 1.

3.3 4.2 Welding processes

The gas welding processes used in the process are : Gas Tungsten-Arc Welding (GTAW) and Gas Metal Arc Welding (GMAW). Gas Tungsten-Arc Welding is an arc welding process that maintains an electric arc struck between a tungsten electrode and a metal work piece which provides the necessary heat for the welding process. The weld zone is protected from atmospheric contaminants by a shielding gas fed through the welding torch. This prevents the weld from becoming porous and weakened by the oxygen, nitrogen, and other gases and other vapours present in the atmosphere. Argon and helium are the typical gases used for GTAW, although argon is usually preferred because of its suitability for a wide variety of metals, the lower flow rates required, and its better arc stability. Either a DC or AC power supply may be used for GTAW. The DC welding circuit may be hooked up in either straight polarity (DCSP) or reverse polarity (DCRP). In DCSP, the electrons flow from the electrode to the plate and hit at a high velocity which exerts a high heating effect on the plate. This forms a narrow weld with deep penetration. However, in DCRP, the electrode receives the extra heat which tends to melt off the end of the electrode. As a result, a larger diameter electrode is required for DCRPwelding. Furthermore, the increased size of the electrode and lower current forms a wide weld with shallow penetration. The AC welding circuit is a combination of DCSP and DCRP. It is a common practice to superimpose a high-voltage, high-frequency, low-power current on the AC welding current to compensate for any oxide film that could form on the metal work piece. The GTAW process uses non consumable, tungsten electrodes that may be pure tungsten or thoriated, zirconiated, ceriated or lanthanated tungsten. The current carrying capacity of the electrode increases as the size of the electrode diameter increases. Furthermore, the current carrying capacity is also dependent on the type of electrode; for instance, the current carrying capacity of pure tungsten electrodes is lower than alloyed tungsten electrodes. The current would need to be increased for thicker samples in order to input enough heat to weld the extra material. As current applied increases up to about 200 amps, a water-cooled torch must be used instead of a gas-cooled torch in order to supply sufficient cooling to the electrode. The two different torches are pictured in

Figure 4.1. In general, GTAW is used for the welding of butt, lap, edge, corner, and tee joints. Some advantages of GTAW include: good weld bead control, high precision on the location and spread of the arc, and low spatter.



Gas-cooled GTAW torch allows the tungsten electrode to be cooled by the relatively cool shielding gas flow.

Water-cooled GTAW torch feeds water through the torch in order to cool the electrode.

Figure 4.1 - Gas cooled and water cooled GTAW welding torches

The collet houses the electrode, which is threaded into the collet body which holds the collet and electrode in place. The cup is used to keep the flow of the shielding gas flowing toward the weld pool.

During the GTAW process, it is important to be careful not to dip the tungsten electrode into the weld. By dipping the tungsten electrode into the weld, discontinuities and defects may be formed that impair the performance of the weld. These discontinuities, known as tungsten inclusions, embed particles of tungsten from the electrode into the weld. As a result, the defects serve as an area of concentrated stress and lower the quality of the weld.

Gas Metal Arc Welding is a gas shielded-arc welding process that gains its welding heat from an arc between a consumable electrode and a work piece. The electrode (which is also the filler wire and is generally of a similar composition to the metal being welded) is melted and transferred to the joint and fused to the work piece by the arc. Like GTAW, the GMAW process requires a gas to shield the weld from the atmosphere. A high electrode current density is required for the metal from the electrode to be transferred to the work piece. The power source of GMAW welding has "drooping volt-ampere characteristics"; the voltages of the machine decrease as the welding current increases. The electrode used is based on:

- The alloy matching the base metal,
- Metallurgical control of grain size, segregation, etc.,
- De-oxidation, and
- The assurance of arc stability and metal transfer characteristics

Table 4.1shows typical current ranges for different wire diameters. Some advantages of GMAW include its wire feeding capability which allows long weld beads to be deposited, its wide use as a robotic arc welding process, and its ability to be used in all positions.

Table 4.1 - Typical Current Ranges for Different Wire Diameters Used in the GMAW Process[16]

Electrode Diameter (mm)	**Usable Current Range (A)**
0.9	60–280
1.2	125–380
1.6	275–475

Base Metals

The chemical composition of A36 can be found in Table4.2. The AWSD 1.1: Structural Welding Code for Steel as well as B4.0M: Standard Methods for Mechanical Testing of Welds and B2.1: Specification for Welding Procedure and Performance

Qualification are used to qualify the A36 steel WPSs.

A 36 is a low carbon steel alloy and is readily welded by all welding processes. It is used in the construction of bridges, buildings, oilrigs, gears, and machinery parts to name a few. Welds formed with A36 steel are of excellent quality and this makes it suitable for structural applications. Hardenability is defined as the ability of a material to form martensite, a microstructure that is prone to cold cracking when around a weld region. One method of predicting a material's hardenability is with the carbon equivalent (CE)formula. This formula equates the relative hardening contribution so far steel's constituents to the most significant hardening agent, carbon. However, it is generally believed that steels having low CE values are immune to weld cracking problems.

When welding A36 steel, it is important that the material is cleaned thoroughly before any welding begins. If the material is not cleaned, contaminants in the form of dirt, oil, oxides (in the form of corrosion), and surface treatments can easily form defects in the welded joint.

The high phosphorous and sulphur content inA36 steel (>.03%) make this material susceptible to hydrogen embrittlement after welding. Embrittlement of this material is due to the presence of hydrocarbons or water vapour during the welding process. To be sure that this does not occur, weld joints and adjacent areas must be cleaned before welding and the shielding gas must be placed over the weld pool properly during welding. A preheat or post-weld heat treatment may also help reduce the effects of hydrogen induced cracking.

Any heat treatment and process history of the base metal should be documented; as different heat treatments react differently to the heat generated during the welding process (e.g. strain hardened materials lose all strength gained from the process near the weld).

Electrodes and Filler Metals

The electrode tip configuration is a significant process variable for GTAW. When dc welding, the electrode tip is ground to a specific angle obtained by a process called grinding. Grinding is another shaping process; in this process the tip is ground with the axis of the electrode parallel to the spinning direction of the grinding wheel, which can be seen in Figure 4.2. The tip geometry affects the weld bead shape and size. As the tip angle increases, the weld penetration increases and the width of the weld bead decreases. Furthermore, it is critical to keep the same electrode tip shape throughout an entire welding process because it can drastically change the weld bead shape and size.

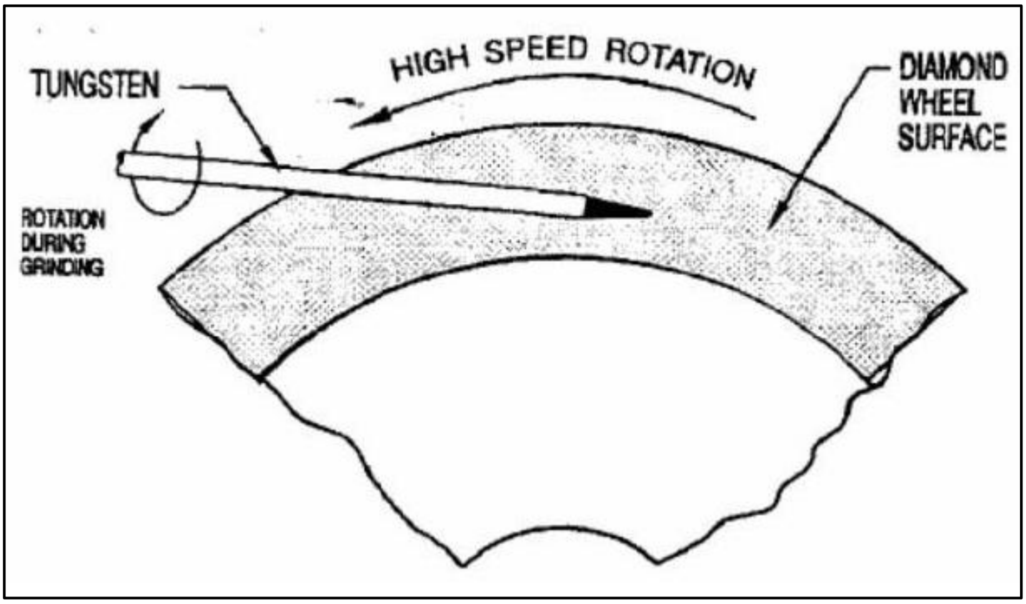


Figure 4.2 - Tungsten electrodes are ground with the tip parallel to the rotating axis of a grinding wheel while the electrode is rotated to produce an even finish [7]

Selecting the right filler metal is important for both GMAW and GTAW welding. Specific filler metals are chosen based on their chemical composition which must be close to or matching the base metal composition. Filler rod diameters are selected depending on the type of metal transfer and base metal thickness.

The filler metals used are ER70S -2 and ER70S-6 for GTAW and GMAW, respectively. ER70S-2 and ER70S-6 are carbon steels alloyed with high amounts of silicon and manganese, which are both deoxidizers. Deoxidizers help prevent oxides from forming in the weld when welding with the highly reactive carbon dioxide shielding gas. The mechanical properties of the filler metals, along with their corresponding base metals, are summarized in

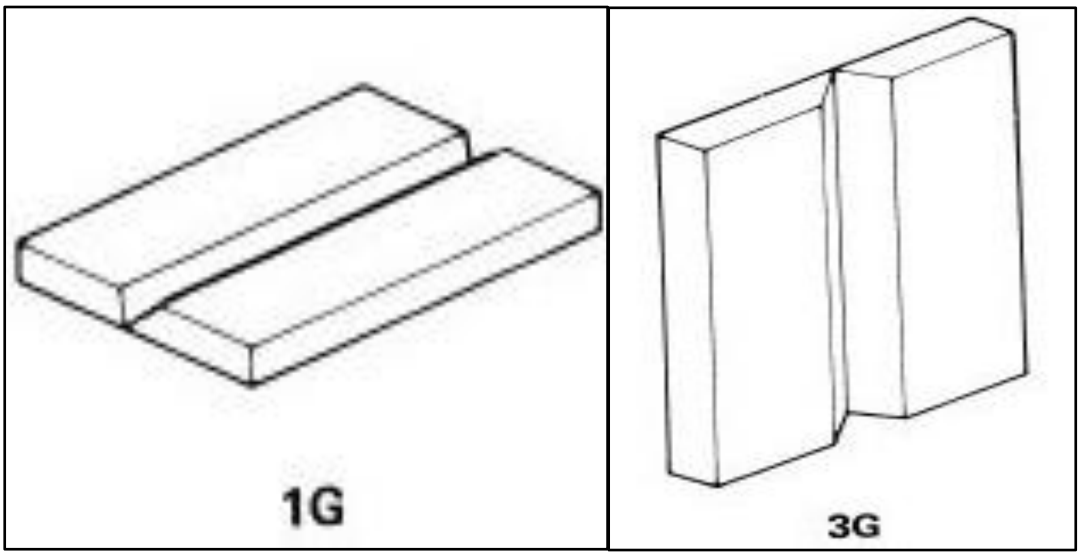
Table 4.2. The certificates of conformance from the supplier for ER70S-2 and ER70S-6 shall be obtained.

Table 4.2 - Tensile and Yield Strength of Base and Filler Metals

Filler/Base Metal	Tensile Strength (N/mm^2)	Yield Strength (N/mm^2)
A36 Steel	400-552	249
ER70S-2	483 min	400 min
ER70S-6	497 min	414 min

Welding Positions

The positions used when welding for the qualification of the welding procedures were the 1G and 3G positions. The 1G position is shown in Figure 4.3 a where the plate was laid flat and secured with clamps and tack welds; welding is then performed horizontally. The 3G position is shown in Figure 4.3b, where the plate is secured vertically and the weld is performed vertically.



a. welding performed horizontally   b. welding performed vertically

Figure 4.3 - Welding positions 1G and 3G[7]

Shielding Gases and Gas Flow Rate

The effects of various shielding gas compositions on the weld bead shape for steel are shown in Figure 4.4. For this project, 100% argon gas was used for GTAW welding and a mix of 75% argon/ 25% CO2 gas was used for GMAW welding. The 75% argon/ 25% CO2 gas mixture was selected to minimize weld spatter of the weld puddle and produce a clean weld.

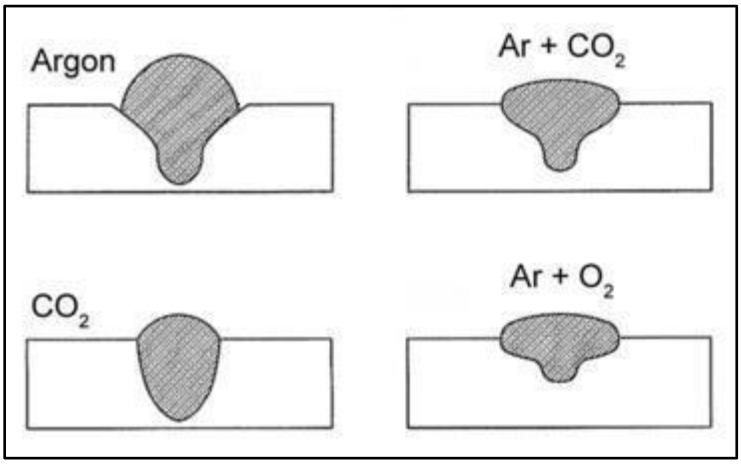


Figure 4.4 - The effect of shielding gas composition on the weld penetration and bead shape for steel[7]

The selection of gas flow rate depends on nozzle size and desired weld pool size. The gas flow rate increases proportionally to the cross-sectional area of the nozzle used in the welding torch. The typical shield gas flow rates for argon are 30 to 60 cf/hr (7 to 16 L/min.).

5 ISSUES IN EMPLOYING ACCREDITEDWELDERS

In the Sri Lankan context, the following practical problems are encountered in the industry and how to control and assure quality in such a scenario is discussed here.

Lack of qualified welders

In view of availability of qualified welders for the industry, it is quite evident that this is a common problem encountered in the boiler manufacturing industry in Sri Lanka. The government policy of vocational training in respect of welders has not been able to produce required number of qualified welders for the industry. Therefore, the boiler manufacturers have had to get the service of unqualified welders inevitably even though they are willing to get the service of well qualified welders.

Remedy:

As this is a long felt need for the industry, the government must be influenced by the relevant stake holders of this industry or business so that the resources allocated for the vocational training of welders shall be increased. Further in view of increasing the number of qualified welders in the country as a whole, Ministry of Labour and Ministry of Vocational Training will jointly implement a project in recognition of the national requirement and to produce required number of qualified welders accordingly.

While taking such steps as long term solutions, the unqualified welders shall be given an opportunity to develop their skills so that they will become qualified welders by introducing 'short courses' in the vocational training centres.
In addition to that they may be provided with financial assistance such as bank loan schemes for them to be motivated. These loan schemes will have to be funded by Ministry of Labour and Ministry of Industries jointly.

High cost of getting services of qualified welders

Since the required number of qualified welders is not available in the industry, the demand is high and as a result of that the cost involved in getting the service is high. This affects adversely in view of the development of the industry.

Remedy:

Increase of number of qualified welders will make a direct impact on the cost reduction because the higher the supply, the lover the demand. However such a process will take some more years to be implemented. Therefore it is more practicable to plan and design some short courses to be followed by unqualified welders so that they can get required knowledge and experience in order to become qualified welders as discussed in “a” above. Meanwhile manufacturers who are willing to get the service of qualified welders might be facilitated with concessionary loan schemes or tax concessions.

Lack of awareness of welding quality control and quality assurance

In view of the current local methods and the standard requirements that have been adopted, it must be emphasized that most of the manufacturers are reluctant to provide such information regarding their welders.

However, it was observed that most of the manufacturers got used to practice electric arc welding for the purpose. Therefore, the welding process shall strictly be adhered to the following procedures since quality control and quality assurance of welding is another important and crucial point of control of the process of boiler manufacture. After the prescribed welding process becomes a part of the law of the country as discussed in ‘Legislation’, that will be the responsibility solely of the inspecting engineer who is the representative of the inspecting authority to implement procedure as a whole, depending on the reports prepared by the authorized certification bodies.

It is of utmost importance that the certification body is an accredited body for the intended purpose.

6 QUALITY ASSURANCE

6.1 Introduction

In pressure vessel welding, quality control and quality assurance is to be regarded as an essential and crucial step of the boiler manufacturing process. However, the quality assurance can be considered mainly under two aspects as:

- Quality of the weld
- Welder qualification

And it is quite evident that these two are inter related. Therefore, it is very important to pay necessary attention by both manufacturers and inspecting engineers during the process.

6.2 Application and Scope

01. These standards apply to all welding pertaining to the construction, fabrication, alteration or repair of any boiler or pressure piping and all such welding shall conform strictly to ASME codes.
02. All welding will be subject to 100% X-ray, but this amount may be reduced at the discretion of the inspecting engineer or his representative depending on the consistent good quality of the welding.

6.3 Welder's responsibility

01. No welder shall weld upon any boiler or pressure piping within the legal entity unless such person is the holder of a valid pressure welder's certificate issued by the department.
02. No welder shall weld by any procedure or position for which he has not been qualified in accordance with these standards.
03. No welder shall make any welded repairs upon any boiler or pressure piping unless such welding is in accordance with these regulations.
04. Every welder holding a valid pressure welder's certificate shall apply to the department within twelve months of the issue date thereof for an annual retest.
05. Where such application in subsection (4) has been made and the depart-

ment is unable to administer a retest, the pressure welder, upon receipt in writing from the inspecting engineer, may continue to do pressure welding until notified of a date for retest. This continuation shall not extend beyond six months of the expiry date of his pressure welder's certificate.

6.4 Pressure welder's qualification tests

01.

a} Pressure welders' basic qualification tests shall be as outlined in these regulations and designated P1-F3 procedures by A.S.M.E. code.

b) All other higher level tests shall be conducted as outlined in section IX of the A.S.M.E. code and these regulations, and the pressure welder to be tested must hold a valid P1-F3 basic certificate.

02.

a) For an annual retest a welder may be tested P1-F3, P1-F3 and 4 or P1-F4.

b) All P1-F3, P1-F4 or P1-F3 and 4 pressure welder's qualification tests shall be made on 15 cm A-106B schedule 80 pipe or equivalent. Semi and fully automatic welding tests shall be made on plates 0.6 m long.

03. The test nipples needed for tests in subsection (2) will be supplied by the department at cost, if required.

04.

a) Where a person fails a coupon in his first qualification test to become a pressure welder it will be considered a complete failure and he will have to wait one month before a retest.

b) On an annual retest if a pressure welder fails one coupon in one position an extra coupon shall be cut in the position failed and if it passes, the pressure welder's certificate will be renewed.

c) Where a pressure welder fails the extra coupon a complete retest will be required at a time set by the inspector.

05. The pressure welder's certificate issued as a result of successfully passing the test will be valid for twelve months subject to section (4),(5) and subsection (6) hereof.

06. A welder may be requested at any time to take a test if he is suspected of losing his proficiency.
07. Persons testing for semi or fully automatic welding will not be required to hold a pressure welder's certificate authorized by the legal entity. Upon successful completion of the test they will be issued a certificate specifying the kind of welding they are authorized to perform.
08. Every application for a pressure welder's qualification test shall be subject to the approval of the inspecting engineer or chief inspector. The basis on which such approval will be granted shall be:
    a) The possession of a valid journeyman welder's certificate; or
    b) Three years of experience as a welder and this experience to be verified by letters or affidavits on official stationery or in a manner acceptable to the inspector or chief inspector.
09. Inspection of test welds will be by face and root bending and by visual examination as follows:
    a) The root pass shall not have excess penetration or burn through;
    b) The finish pass shall be neat and uniform in width without undercut or excessive overhang.

Information respecting welders' qualification tests

01. A welder must be tested in all methods and types of welding and for every position in which he will be required to weld, provided that if a welder successfully passes a butt weld test an inspector may in his discretion waive the requirements for a fillet weld test for the same position.
02. A welder must qualify for all positions before an authorization can be issued him for welding pressure piping in fixed position.
03. Test welds upon 9.5 mm thick material qualifies a welder to weld material to 19 mm thickness by the electric arc process. Test welds for qualifying a welder to weld material thicker than 19 mm shall be upon material of the maximum thickness to be welded except that no test weld needexceed2.5 cm in thickness. For gas welding this maximum thickness for which a welder is qualified shall be that of the test coupons.
04. Every test shall be witnessed by an authorized inspector who shall stamp each coupon to denote the test position. All stamping shall be done upon

the face side and a punch mark shall be stamped on the ground edge of each coupon to denote the centre of the weld.

05. The various welding positions for test specimens and the procedure for cutting coupons from same are shown in the A.S.M.E. Welding Code.

    NOTE: Total length of welded test specimens should not exceed 21.6 cm.

06. Weld test specimens are to be flame cut to coupons 2.5 cm wide and all excess weld material must be ground off by the welder. Care should be taken that coupons are not ground excessively so as to reduce their thickness.

07. Successive layers deposited during weld test may be chipped or otherwise cleaned. Defects made during weld test may be removed by chipping, grinding or any other approved manner provided such corrections are made from the face side only of the test specimen. Stops and starts are not considered to be defects but they may be ground on stainless steel tests only.

08. Test coupons will be given root bend, face bend, elongation and nick break tests by the department.

09. Bend tests which show any crack, opening, or other defect exceeding 3.2 mm measured in any direction, shall be considered as having failed, provided that small cracks (not slag or gas pockets) occurring on the corners of test coupons shall not be considered.

10. Nick break tests shall show complete penetration and absence of slag inclusions, gas pockets, un-welded metal or crystallization.

11. A registered welder if changing his place of employment, should notify the department before undertaking any pressure welding for his new employer. The department will then determine whether he shall or shall not be required to undergo a retest and whether he may use the symbol previously allotted or if he shall be issued a new symbol.

12. A welder's certificate expires one year from date of issue at which time he shall apply to the department for an annual retest.

6.5 Stamping of work

01. Every welder qualified under these regulations shall stamp his symbol upon all work done by him in the following manner:

a) On new work including pressure piping, at 1 m intervals along all seams and joints and on each separate weld;

b) On repair work at 0.3 m intervals along all seams and joints and on each separate weld. On boiler tubes and special jobs where symbols cannot be used a record of welders doing such welding shall be kept and submitted to the department.

02. No work is to be covered or insulated until inspected by the inspecting engineer and the above stamping shall be readily visible.

03. Where for any reason a pressure welder's certificate is cancelled or has expired, no further use shall be made by the welder or his employer of his assigned symbol or pressure welder's certificate. The pressure welder's certificate and his assigned symbol shall be surrendered forthwith to an inspector or be forwarded to the department.

04. Where a welder qualified outside the province welds on boilers, pressure vessels or pressure piping for use in the province the use of his assigned symbol and the stamping of his work shall meet the requirements of this section.

05. A person's pressure welder's certificate shall be cancelled if he:

a) Fails to stamp his work with the symbols assigned him;

b) Stamps work not performed by him;

c) Allows another person to use his assigned symbols;

d) Consistently does poor pressure welding.

6.6 Manufacturers and contractors responsibility

01. Every manufacturer, contractor, installer, welding shop operator or other person who welds or employs any person to do any welding upon any boiler or pressure piping shall:

a) Be responsible for the quality of the welding done thereon by him or his welders; and,

b) Formulate a welding procedure and have such procedure registered. This procedure, if formulated in the legal entity, shall be tested and approved and if formulated outside the boundaries of this jurisdiction, the procedure must be tested and approved by the jurisdiction concerned and notification of same submitted to the department;

c) Arrange with the inspecting engineer for a qualification test of every welder to be employed using an approved procedure and conducted by an authorized inspecting engineer.

d) Issue to any pressure welder in his employ a symbol for stamping his work and notify the department to whom such symbol is issued.

02. The department shall issue symbols to pressure welders who are self-employed;

03. No welding shall be done upon any boiler or piping unless the above requirements respecting procedure tests and pressure welder qualification tests, including tests of welding machine procedures and welding machine operators where used, have been complied with and certified data respecting all such tests have been submitted and approved.

04. Every manufacturer, contractor, installer, welding shop operator or other person who employs any person to do welding upon any boiler or pressure piping shall be responsible for the stamping of all such welding by the pressure welder with his allotted symbol in accordance with these standards.

6.7 Repairs to boilers and pressure piping

01. No welded repairs shall be made upon any boiler, pressure vessel or pressure piping unless:

a) The welder is the holder of a valid all position pressure welder's certificate signed by the inspecting engineer;

b) Permission is first obtained for the repair from the inspecting engineer or his representative;

c) Upon completion of the repair the department shall be notified and an inspection made before the repaired unit is returned to service.

02. No welded repair shall be made upon any boiler, pressure vessel or pressure piping where such welding is required by the A.S.M.E. code to be stress relieved and x-rayed except it be done in accordance with an approved procedure and under such conditions as meet all A.S.M.E. code requirements and are satisfactory to the inspecting engineer.

03. No welded repair shall be made on any boiler, pressure vessel or pressure piping by other than electric arc process and under no circumstances shall any welding be done on any boiler, pressure vessel or pressure piping which is under pressure.

6.8 Classification of pressure piping

The following piping shall be considered pressure piping subject to all the requirements of these regulations:

a) Steam piping of any size or pressure;

b) Water piping to carry hot water at more than 66°C;

c) Piping to carry refrigerants, anhydrous ammonia, propane or similar gases;

d) Air piping larger than 2.5 cm nominal pipe size;

e) Oil piping larger than 2.5 cm nominal pipe size to carry hot oil at more than 66°C;

f) Pipe headers and other piping used directly in connection with any oil field vessel;

g) Any other piping used in connection with or as a part of, a boiler, pressure vessel or pressure piping installation and classified as pressure piping by the inspecting engineer.

6.9 Welding of pressure piping

01. Any welding of pressure piping shall conform to these regulations and the inspecting engineer shall satisfy himself that:

    a) The welder holds a valid pressure welder's certificate for the procedure used;

    b) The procedure to be used has been properly established and registered;

    c) Any test witnessed by him is acceptable for proving both the qualification of the welder and correctness of the procedure; or

    d) Where separate tests are necessary to establish welder qualification and procedure correctness, especially where piping or weld metal is of alloyed material that these separate tests are performed.

02. All pressure piping shall, if 7.6 cm or larger nominal pipe size, be welded by the electric arc process.
03. Seal welding of threaded joints may be used when approved by the inspecting engineer but shall not be considered as contributing to the strength of the joints.
04. Thickness of pipe to be used in any installation shall be determined by the applicable formula of the A.N.S.I. Pressure Piping Code and electrodes or filler metal shall conform to the requirements of Section IX of the A.S.M.E. code and have an acceptable A.W.S.–A.S.T.M. designation approved by the American Welding Society for the class of work to be performed.
05. Welding of branch connections, fittings and flanges shall meet all the requirements of the A.N.S.I. Pressure Piping Code and these standards.
06. Where backing rings are used they shall be thoroughly fused with the pipe while welding and shall be of a material similar to the pipe being welded. In no case shall backing rings have a sulphur content in excess of 0.05 percent.
07. Ends of all piping to be welded shall be welded to an angle of approximately37.5° and shall be thoroughly cleaned of all rust, grease, paint, scale, slag or other foreign materials.
08. Visual inspection of welds shall comply with the following:
    a) Root pass shall not have excess penetration or burn through;
    b) The finished weld shall be neat and uniform in width without undercut or excessive overhang.
09. No two beads shall be started at the same location and extreme care shall be taken to obtain full root penetration with the first bead with a minimum of weld material projecting within the pipe.
10. Piping before being welded shall be carefully aligned so that no part is offset with respect to an adjacent part after welding by more than 0.2 of the pipe thickness and, the finished weld shall have a reinforcement of not less than 1.6 mm nor more than 3.2 mm the width of the weld with no undercuts at the edges of the weld.
11. When tack welds are used they shall be made by an authorized pressure welder in accordance with the approved procedure or shall be removed

during the welding operation.

12. Preheating and stress relieving shall be done in accordance with procedures outlined in the A.S.M.E. codes.
13. No welding shall be performed when the metal temperature is below -18°C and when the metal temperature is between -18°C and 0°C the area adjacent to the required weld shall be heated to approximately 21°C before welding. No piping shall be welded during rain, snow or high wind unless the work and the welder are protected there from.

6.10 Inspection of pressure piping

01. All pipe welds, unless otherwise approved by an inspector shall be hydrostatically tested to one and one half times the working pressure in accordance with the A.N.S.I. and A.S.M.E. codes.
02. All pipe welds shall be subject to examination by x-ray.
03. Testing methods shall be in accordance with the A.N.S.I. Pressure Piping Code and the A.S.M.E. Code.

6.11 Inspection general

For the purpose of these standards an inspecting engineer may:

01. Exercise any powers authorized by this standard or any other applicable section of the Act where deemed necessary;
02. Inspect or re-inspect any boiler, pressure vessel or pressure piping which is being constructed, altered or being repaired by welding or subject it or require it to be subjected to any hydrostatic test, x-ray examination, or any other test which in his opinion is necessary to determine the safety thereof;
03. Require any welding removed which in his opinion does not meet all the requirements of these standards;
04. Seal any boiler, pressure vessel or pressure piping welded by a welder not holding a valid pressure welder's authorization meeting the requirements of these regulations or welded contrary to an approved procedure or without an approved procedure or which in any other manner violates the requirements of these standards.

6.12 Testing of welders and procedures

The testing of welders and of procedures by department inspectors for the welding of pipelines not subject to the requirements of the standard, may be arranged with the inspecting engineer who together with the contractor, engineering agency or other body responsible for the pipe-line construction shall specify the standard to be used for such tests which as far as is practicable shall be in accordance with A.N.S.I. Code B31 series. In such tests the contractor, engineering agency or other body shall supply all test materials.

6.13 Welding procedure qualification (WPQ) of A36 steel plates

As an alternative to the specified materials for standard requirements, A36 steel was selected and a welding procedure qualification would be proposed as follows.

6.13.1 General

Qualification is to be performed using both 1G(flat) and 3G(vertical) positions for Gas Tungsten Arc Welding (GTAW) and Gas Metal Arc Welding (GMAW) processes. Required qualification procedures included two face and two root bend tests coupled with a visual inspection for cracks within the weld region greater than 3 mm long, along with two reduced section tensile tests to ensure the tensile strength exceeded 400 N/mm^2 if the sample broke within the weld region or 380 N/mm^2 if the sample broke outside of the weld region. Tests are standardized by using American Society for Testing and Materials(ASTM) standards. Cracks greater than 3 mm are found in the weld region of bend tested samples in each process except for the 3G GTAW, disqualifying them.

Introduction

Welding Procedure Specifications are written, qualified welding procedures that provide direction for making production welds to code requirements. Completed WPSs describe all essential and nonessential variables per welding process used in the WPS. The necessary variables that must be met are in accordance with a set of standards that have been written and published. After being written, a WPS typically must be qualified by a number of mechanical tests and visual inspections that are required by the relevant codes such as AWSD1.1and B4.0 standards and defined by ASTME 190-

14 and A370-15, for U. S. A. The results of the test are written in a Procedure Qualification Record (PQR), which is later attached to the WPS to notify the welder that the WPS has been qualified and can be followed to perform welds and certify welders. The list of process/base material/position combinations evaluated in this project are summarized in Table **6.1**.

Table 6.1 - Process/Base Material/Position Combination of Welding Procedure Specifications[7]

Process	**Base Material**	**Position**
Gas Metal Arc Welding	A36Steel	1G(Flat)
Gas Metal Arc Welding	A36Steel	3G(Vertical)
Gas Tungsten Arc Welding	A36Steel	1G(Flat)
Gas Tungsten Arc Welding	A36Steel	3G(Vertical)

WPSs consist of essential variables and nonessential variables. Essential variables are factors that cannot be changed in the specification without the specification having to be re-qualified. The essential variables shall include

- Welding process
- Base metal
- Filler metal
- Electrode
- Position
- Shielding gas
- Gas flow rate
- Preheat and Inter-pass temperatures
- Post-weld heat treatment

Nonessential variables are parameters in the WPS that can be changed without the need for requalification. However, an on essential variable for one process may be an essential variable for another. The nonessential variables may include.

- Supplied Voltage
- Supplied Amperage
- Travel Speed
- Some Joint Designs

Qualification

In order to qualify a WPS, the proposed weldment must demonstrate the mechanical properties required by the standards. (AWS for USA). Test plates are welded according to the specified procedure by certified welders, which are then sectioned by flame cutting as specified by AWSD1.1. The ends of the test plates are discarded because they may have been welded at a different rate and tend to have higher impurity content than the rest of the weld bead.

Procedure qualification record

Procedure Qualification Records (PQRs) are support documents for the WPS, which document the results of the tests required by the standards used. Required tests include visual inspection, two root bend tests, two face bend tests and two reduced section tensile tests as specified in AWSD1.1 and B2.1. The bend tests are performed in accordance with ASTM E 190-14 and the tensile tests are performed in accordance with ASTM A370-15. APQR is typically signed by the visual inspector of the bend tests as well as the technician who performed the bend and tensile tests.

Acceptance criteria

Visual inspections are conducted prior to mechanical testing of the welds as a preliminary method of assessing the soundness of the weld. Visual inspection in the form of a dyepenetrant test are performed on the welds after bend tests are conducted to measure crack lengths within the weld region. Visual inspection of groove welds will have to meet the requirements set forth by AWS D1.1. In order to pass the tensile test, the strength of the weld shall not be less than the minimum specified tensile strength of the base metal or the weld metal (lower of the two). However, if the specimen breaks in the base metal outside of the weld or fusion line, then the test shall be accepted, provided the strength is not lower than 5% below the minimum specified tensile strength of the base metal.

Passing the bend tests requires that the weld and heat affected zone, of a transverse weld-bend specimen, be completely within the bent portion of the specimen after testing. The guided-bend specimen shall not have opened defects in the weld or heat affected zone larger than 3 mm in any direction on the convex surfaces after bending.

Heat affected zone

The heat affected zone (HAZ) is the section of the base metal that is subjected to high enough temperatures caused by the welding process to affect the metallurgical structure. The microstructure of the HAZ is different than the pre-weld base metal microstructure and can be divided into 9 zones, some of which are illustrated in Figure 6.1

01. Complete mixing
02. Unmixed region
03. Partially melted
04. Grain coarsened region
05. Grain refined region
06. Partially transformed region
07. Spheroidized
08. Strain aged

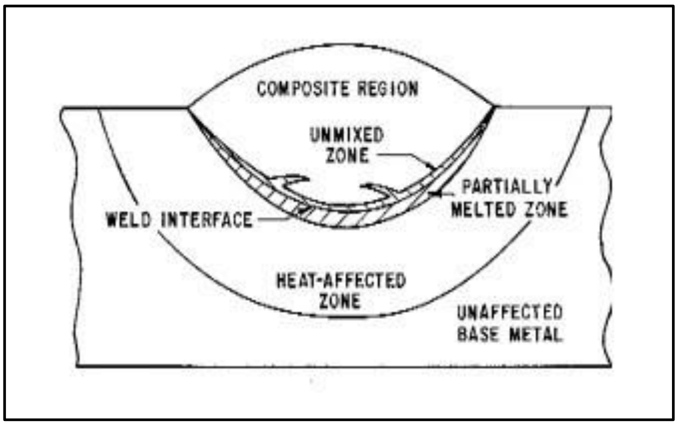


Figure 6.1 - The Heat Affected Zone is the immediate area surrounding the weld that is mechanically affected by the heat of the welding process[7]

Additionally, the HAZ properties and microstructure are dependent on

- The rate of heat inputand cooling
- The zone's peak temperature during the welding process
- Original grain size, grain orientation, and degree of prior cold work

The HAZ metallurgical characteristics directly influence the weld mechanical properties and joint performance. Smaller grains are formed from a system with lower current levels; the low levels of energy input encourage rapid cooling and a faster weld solidification rate. Inversely, with higher current and heat input, the cooling rate is slowed and coarse grains are produced. Therefore, a HAZ that has extremely large grains is an indication that high amperage or slow travel speed was used during welding. Coarser grains in the microstructure are typically a cause of lower hardness and lower tensile strength.

Inclusions

Inclusions are compound materials that are introduced into the base metal during the manufacturing process. Too many inclusions may affect the mechanical properties of the base metal. There are two types of inclusion classifications: indigenous oxygen, sulphur, carbon, nitrogen, etc. Furthermore, they can be caused by the cooling of the melt due to changes insolubility and are usually between 50-100 μm in size. Exogenous inclusions, on the other hand, come from sources like refractories or mould coatings that are outside the steel. These inclusions are usually visible to the naked eye on a polished section and are greater 100 μm in size.

Porosity

Porosity is a large problem for welding and is one of the main causes for failure sin welds. Porosity occurs in welds when a gas or water vapour, usually other than the shielding gas, is trapped within the weld during a welding pass. The trapped gas forms a pocket that serves as a stress riser that can reduce the mechanical properties of the weld. If water vapour is trapped instead, the vapour will expand as it is heated, potentially popping the pocket or at very least making it grow significantly. Porosity can also be a problem even if perfect shielding techniques are used because it is often intrinsic to the base metal itself. Porosity is easily spotted within a sectioned weld piece using optical or stereomicroscopy techniques. Porosity can also be easily found within a weld prior to sectioning via radiographic interpretation techniques. These techniques are frequently used to determine the porosity levels, inclusion content, fusion problems and cracking within the weld before testing and therefore often save time and resources. Welded plates are often rejected if it is determined that the weld does not meet the quality requirements or if the defects exceed the allowable requirements of the standard.

6.13.2 Procedure preparation of the specimens

The bulk A36 plates are flame cut into 50 cm x 20 cm pairs of plates with 30° single V-grooves. A grinding saw is used to grind the flame cut portions flush and remove oxide from the vicinity of the groove. After tack welding the plates together, the welder shall weld the front (face) of the groove with 4 passes in either the 1G or 3G position. Between passes, the welder shall remove any oxide with a wire brush. Once the plates cooled, the backs (roots) of the grooves are back gouged with a burr and then root welded with one pass. Bend and tensile test specimens are flame cut from the plate to analyse the welds' tensile strengths and ductility. They are prepared as per AWS D1.1 and the dimensions are given in Table 6.2 below.

Table 6.2 - Specimen specifications for tensile and bend test[7]

Dimension	Bend Specimens	Tensile Specimens
Length	40 cm	40 cm
Width	3.75 cm	5 cm
Thickness	9.5 mm	9.5 mm

After sectioning the specimens, the face of the weld is ground down flush with the base metal using a grinding saw and a belt grinder. The specimens to be tensile tested are milled to the recommended AWS and ASTM dimensions, as seen in Figure 6.2.

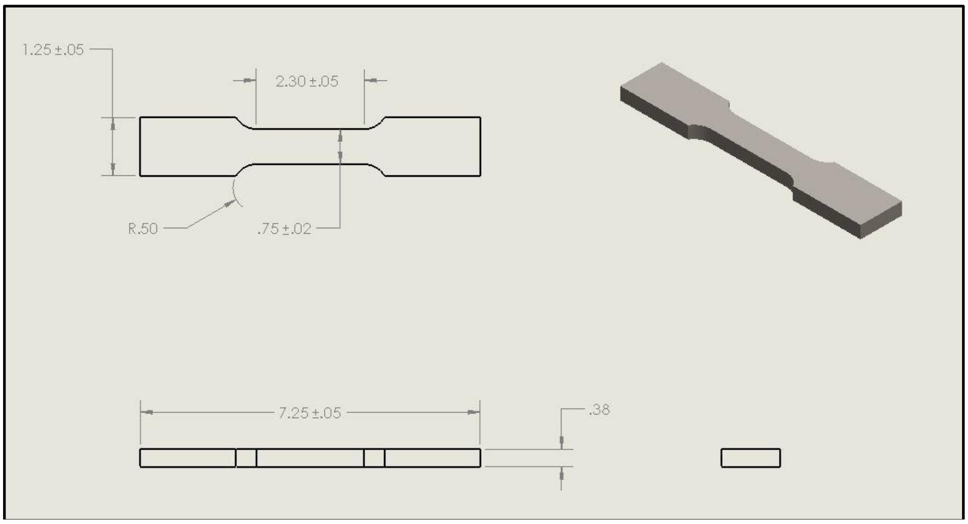


Figure 6.2 - The Heat Affected Zone is the immediate area surrounding the weld that is mechanically affected by the heat of the welding process[7]

6.13.3 Bend testing

Test

The bend test used is the wraparound method to measure the ductility of the weld and can be seen in Figure 6.3.The purpose of the bend test is to ensure the weld and base metal are properly fused and that the weld metal and HAZ have acceptable mechanical properties. Furthermore, when defects in the material exist while being exposed to high strains from the bend test, the material can tear locally and may result in a specimen failure.AWS D1.1 required two face bend and two root bend tests per welding process. These test samples are accepted if no cracks longer than 3 mm are present within the weld region after bending.

Figure 6.3 -The mechanical wraparound bend test measures the ductility of a weld[7]

Reduced section tensile test

The AWS code required at least two specimens from the same plate to exceed a minimum UTS of 400 N/mm^2 if the failure occurred in the weld, or 380 N/mm^2 if the failure occurred outside of the weld. A reduced section weld specimen can be seen being tensile tested in Figure 6.4**.**

Figure 6.4 -The reduced section tensile test measured the tensile strength of a welded sample[7]

Optical microscopy

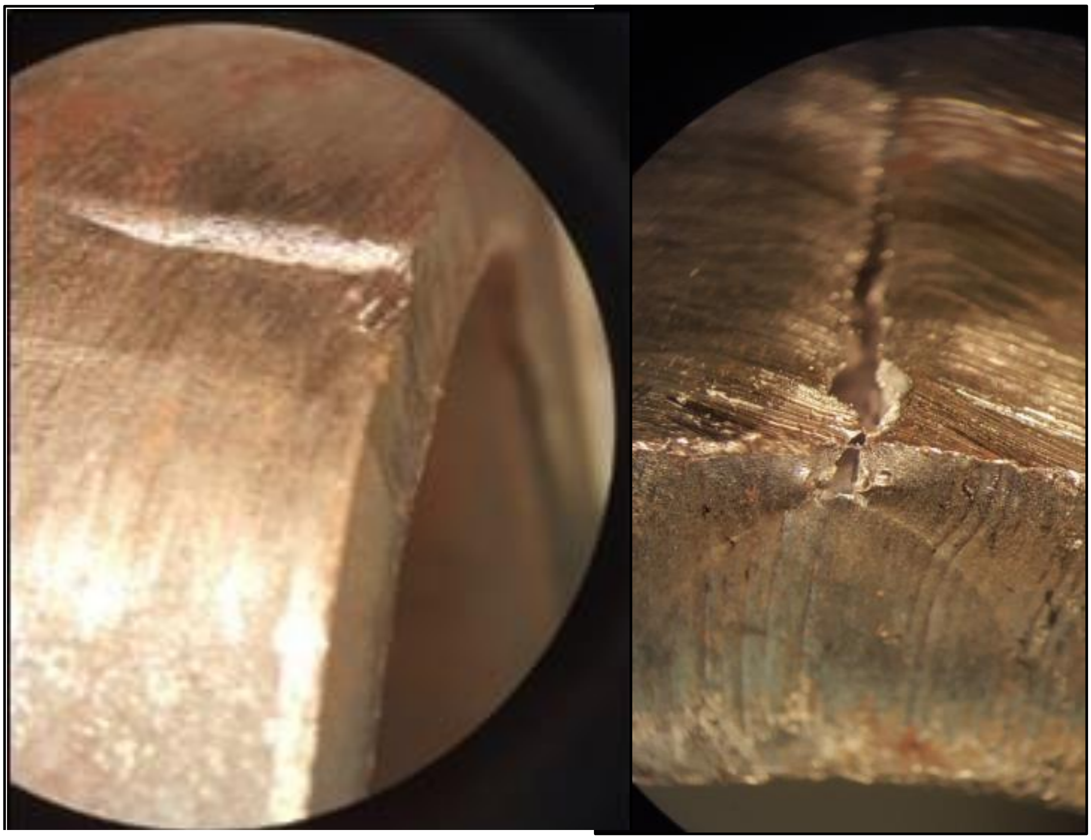
Optical microscopy examination is performed on samples in the as-polished and etched conditions. The samples are inspected in the as-polished condition in order to determine the inclusion type, inclusion content, and porosity levels in the base and weld metal. The samples in the etched condition are inspected to determine the microstructure of the base metal and to evaluate the microstructure of the heat affected zone and weld metal.

Scanning electron microscopy

A scanning electron microscope (SEM) is used to determine the mechanism of failure within the cracks as well as gain an enhanced view of the failures. Energy dispersive X-ray spectroscopy (EDS) is attempted in order to determine the composition of various inclusions and oxides present and observed under metallographic and fractographic examination.

Stereo microscopy

The specimens that failed the bend test, shown in Figur6.5, are submerged in liquid nitrogen and broken along the crack length. A stereo zoom microscope was used to inspect the fractured surfaces of the bend test cracks. The fracto-graphic method aided in determining the causes of failure in the welds.



GMAW 1G bend failure GTAW1Gbendfailure

Figur6.5 - Images of failed bend specimen [7

Dye penetrant visual inspection

Dye penetrant inspection (DPI) is a non-destructive test method that aids in detecting any flaws that are open to the surface of a test piece. Dye penetrant inspection is performed on each sample that is bend tested, shown in

Figure 6.6. The outside convex surface of the bent specimens was coated with a red dye and given a sufficient amount of time for the dye to penetrate any surface cracks. The surface was then wiped clean from any flaw present on the weld surface via capillary action.

Application of the penetrant | After applying the developer to aid in the discovery of cracks

Figure 6.6 - Dye penetrant inspection images[7]

Some of the essential boiler inspection points can be demonstrated schematically as shown in Figure 6.7.

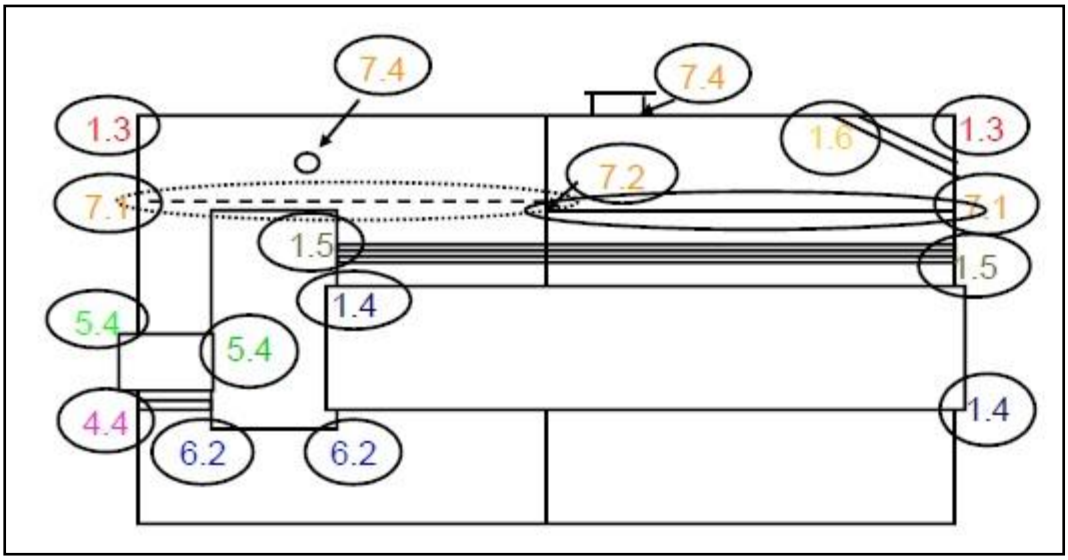


Figure 6.7 - Schematic of boiler showing Critical Inspection Points [8]

List of critical inspection points corresponding to Figure 6.7.

1.3 Plate to shell welds

1.4 Plate to furnace tube

1.5 Plate to smoke tube welds (possibly both ends)

1.6 Plate to gusset stay welds(also gusset to tube plate, see Figure 6.8)

2.4 Smoke tube welds (as 1.5 above)

3.4 Furnace tube welds (all, longitudinal and circumferential)

4.4 Stay bars, both ends and also any bars which join the front and rear tube plates

5.4 Access tube to reversal chamber rear plate and access tube to rear tube plate

6.2 Reversal chamber wrapper plate to tube- and rear-plate

7.1 Shell longitudinal welds, all

7.2 Shell longitudinal weld to circumferential weld Tee Junctions

7.4 Attachment welds (steam outlet, cold water inlet, man-way)

Details of Inspection Points

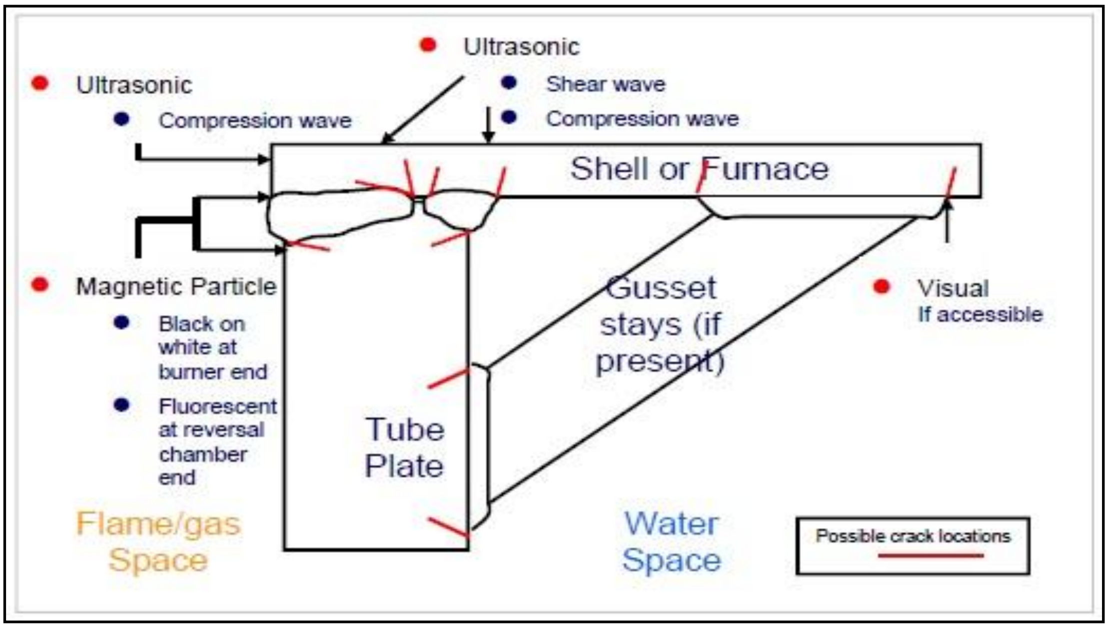


Figure 6.8 - Inspection area 1.3, 1.4 and 1.6 [8]

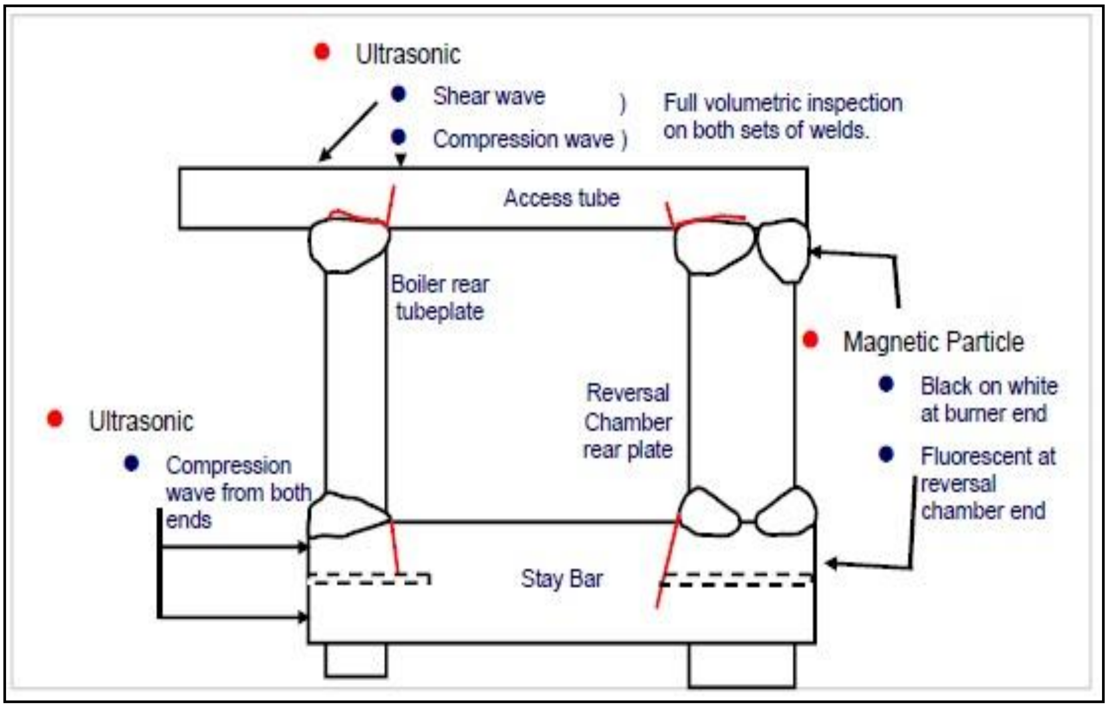


Figure 6.9 - Inspection area 4.4 and 5.4 [8]

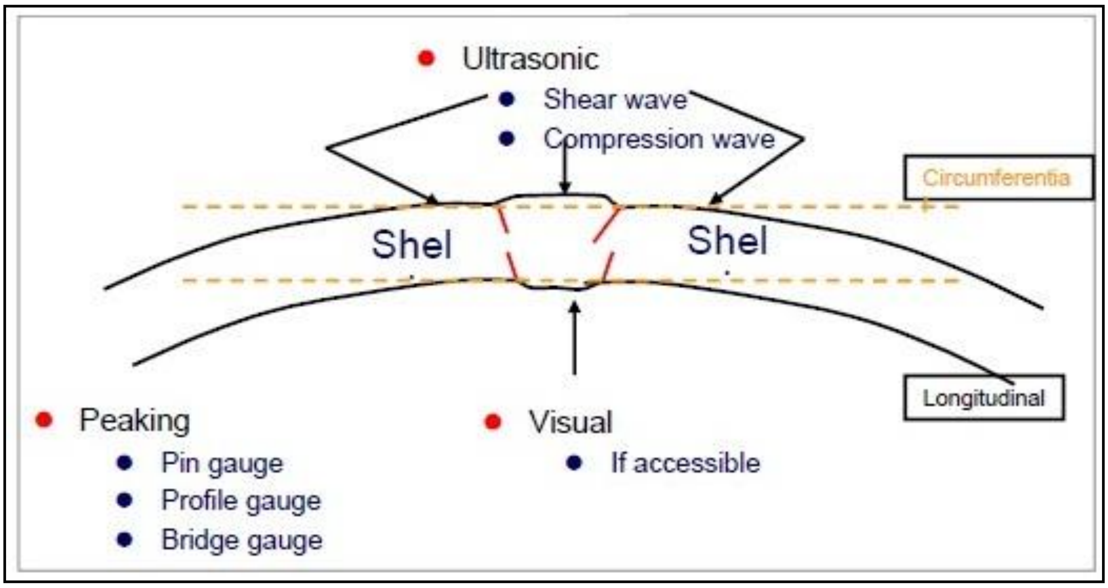


Figure 6.10 - Inspection area 7.1 and 7.2 [8]

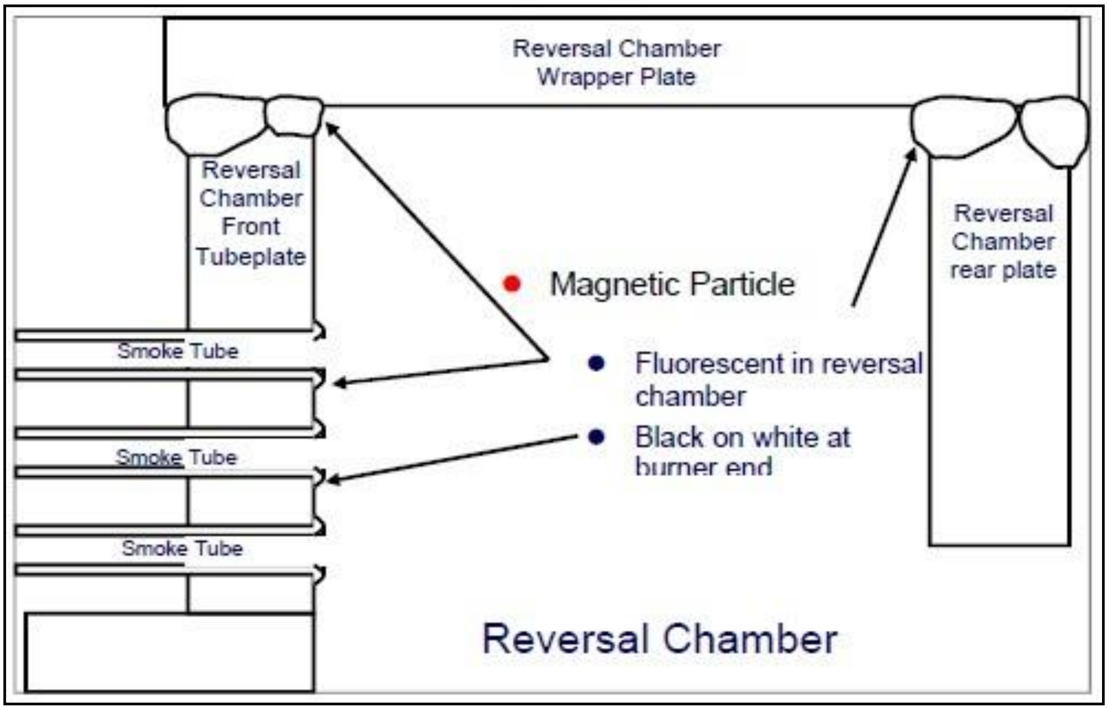


Figure 6.11 - Inspection area 1.5 and 6.2 [8]

7 LEGISLATION AND FINDINGS

7.1 Introduction

Standards are volunteer by nature. Therefore, a legalized process shall be carried out in order to make the standard, a part and parcel of the legal system of the country. This process mainly consists of standards formulation procedures of adoption that are internationally recognized as essential. However, some deviations might have emerged in view of the relevancy of the methodology and the practical problems that had to be confronted with. For example, in case of root cause analysis as described in **7.11**, it is highly dependent on the information revealed by the Department of Labour on which the power of investigation is vested solely and the other stake holders such as manufacturers and welders. The legislative process as such consists of following steps.

7.2 Literature review

A comprehensive literature review to assess internationally recognized criteria for the manufacture of boilers is performed**.** Mainly the con-current international standards or codes and their relevancy to the locality are taken into consideration. In view of the scope of this standard, it was decided to derive the assistance from **ISO 16528-** Part 1: Boilers and pressure vessels, **SLS 1512:2015** and the **Indian Boiler Regulations**(**IBR**) in formulating the standard.

7.3 Feasibility study

In view of possible approaches to attend the intended purpose, adoption of an available national standard for the design and manufacture of Boilers, several international and national standards or codes were subjected to comprehensive consideration before essential assistance being derived thereof. For such an approach, the size of the boiler industry of the country and the availability of basic resources would be considered as governing constraints.

7.4 Developing an adopted standard (draft) based on the identified criteria

A committee called 'Working Group' is formed by the 'Sectoral Committee' on which the authoritative power is vested, in order to make final decisions on draft standard developed with the consensus of working group, based on afore said international standards(**ISO**) and codes (**IBR**). The revised draft standard as such is submitted for the approval of the sectoral committee, in order to send it for public circulation.

7.5 Circulation of the draft standard among interested parties

A period of two months is given to interested parties in order to get their comments based on the basic principles of standardization originated from the concept of consensus of majority. Comments received would be through letters posted, faxes and e-mails.

7.6 Analysing the received comments.

Those comments received are referred to the expertise committees in order to get them analysed and to get their consensus for the alterations proposed.

7.7 Finalizing the standard

The adopted standard has to be published after being approved by the council of SLSI. Before being approved by the council, received public comments have to be considered and incorporated as necessary with the approval of relevant sectoral committee.

7.8 Completion of the standard adoption process

After incorporating those approved alterations therein, by publishing it as a National Standard with the approval of the council of SLSI, standard development process is completed. This standard is volunteer in nature.

7.9 Enactment as a law of the country

In order to regulate the boiler industry of the country the adopted standard will be regarded as the base document. Before this being implemented, department of labour will make aware the boiler industrialists and other stake holders of the industry. Necessary amendments to the existing act of department of labour will have to be passed in the parliament in view of the enactment. Inspecting engineer will play a major role in the implementation phase where he will be the decision maker at the user end.

7.10 Implementation

In the implementation phase, based on a report prepared by an accredited testing body which will assess the design and construction as a whole, the Labour Department of Sri Lanka will make their decision so as to permit the manufacturer, whether to continue with his work or what sort of alterations to be introduced, otherwise.

7.11 Introduction to boiler failure analysis

7.11.1 A practical example of boiler failure analysis

A failure of a package boiler installed in a tea factory in the southern province of Sri Lanka is analysed as a case study. This boiler was manufactured and installed by a local manufacturer.

7.11.2 Analysis of alternatively suggested methods in lieu of adopted standard requirements

The materials suggested in the standard framework (Table **2.5-a** and**2.5-b**) are incorporated therein in order to get the standard to be in line with the international standards. However, the Sri Lankan boiler Industry may confront with some practical problems in selecting such standardized materials. Therefore, this analysis is carried out to show the industrialists that the materials available in the market would also be used provided that essential analysis are carried out and the selected materials comply with the standard requirements.

Also the welding procedures that suggested are internationally recognized such procedures and as revealed in the industrial surveys, existing procedures are not up to the required standards. Further it must be emphasized that in case of pressure vessels those welding procedures shall be followed and no other alternative is available.

7.12 A preliminary analysis of failure of a locally manufactured package boiler

7.12.1 Location:

A tea factory in the southern province of Sri Lanka

7.12.2 Details of the boiler:

Wood fired; fire tube package boiler

7.12.3 Objective

Analysis of the root-cause for the explosion of the aforesaid damaged boiler

7.12.4 Preliminary observations

The boiler was damaged beyond repairable condition and to be condemned.

The was fitted with essential safety requirements such as a safety valve, pressure gauges, water level indicator etc.

There was no certified operator in attendance. However, records of the pressure were maintained hourly basis. On the day, the explosion took place the pressure was recorded as follows:1400 hrs–8.2 bar, 15.00 hrs-8.4bar, 16.00 hrs-8.4bar; and 1700 hrs-8.4bar.

Boiler was subjected to intermittent operation. Firing commenced around 08.00 hrs and the fire was put off around 18.00 hrs each day.

Boiler was installed newly and commissioned by the vendor. No document was given to the owners but at the end of one-week trial and testing period the vendor has suggested that working pressure of the boiler should be 8.4 bar.

Vendor has not given any document pertaining to the construction and testing history of the boiler. The following documents were requested but the manufacturer has declined to produce/show any of the following.

a) The design/drawing of the boiler with welding details.
b) The design code.
c) The design pressure, hydraulic test pressure and the date of test
d) Certificate for the safety vale.
e) Calibration certificate of the pressure gauge

Vendor has not appraised of the need of the essential operational require-

ments such as employment of a certified operator.

7.12.5 Secondary observations based on the thorough internal examination:

I, The rear tube plate was sheared off at the circumferential weld joining the fire drum.

II. The fillet weld was found with volume defects (gas/air inclusions or blow

III. It was also found that the circumference of the fire drum did not match the opening on the end plate thus making an excessive gap at some locations. To make the situation worsen the weld from inside was not completed and filled adequately, leaving a sharp v-shaped groove right-along the joint –approximately 200mm in length.

IV. This has resulted a highly stressed/ weak area on the joint due to the cyclic loading pattern (Re-starting every day). The edge of the drum is subjected to repeated loading and flexing under pressure and release of pressure. This obviously has led to the pre-mature failure of the weld.

V. The fire drum was assembled with several butt-joints. The drum was completely deformed but we observed one location with a defect in the weld. The boiler drum (butt welds) should be subjected to 100 % radiographic testing to ensure 100 % joint efficiency as per all known codes and standards.

VI. A visible defect (crack) on the weld indicates a very serious lapse in quality of the weld. In order to ensure the quality of welding the following steps should have been taken during the manufacturing stages:

a) Preparation of a WPS

b) To establish the already prepared WPS with a PQR

c) To qualify the welders in accordance with the WPS. Only the qualified welders to be used for the boiler welding process.

d) All butt joints on the pressure parts to be radio graphed.

e) All fillet welds joining the boiler tubes onto the end plate to be MPI tested for possible cracks.

f) The boiler tubes joining the end plate were not acceptable. Most of them projected outside the end plate thus giving sufficient room for a fillet weld outside whereas some tubes were short in length so the weld had to be deposited inside the end plate. This too is poor quality of construction. Although tube joints did not fail up to now, there is a possibility of failure even in the near future.

7.12.6 Conclusions:

There can be only two probable situations that could result the failure of the boiler:

a. The Boiler pressure initially rising over and above the design pressure and thereafter the test pressure due to malfunctioning of the safety valve.
b. Any of the structural member failing below the design pressure due to either poor quality of material or poor quality of workmanship.

The test certificate for the safety valve was not available. This again is serious omission and lapse. However, the safety valve was stamped with 10 Kg/cm^2 so it is assumed that the Boiler manufacturer has pressure-tested the boiler over and above approximately at 15 bar(There again a record was not available). So only if the boiler pressure has gone above 15 bar, an explosion could take place, in the event the safety valve got stuck.

However, the operation of the safety valve shall be verified by the manufacturer's representatives subsequent to the explosion and safety valve opened at 9 bar (approx.)

Also as per the hourly records maintained at the boiler house the pressure was 8.4 bar at 1700hrs and the explosion has taken place at 1720 hrs and it is very unlikely the boiler pressure could suddenly go up by 7 bar within a short period of 20 min.

Having taken into consideration the above two factual observations the possibility of situation a) could be ruled out easily.

This leaves us with the option of assuming the situation b) and also there had been ample of supporting evidence for this mode of failure. The overall quality of workmanship was poor and the Quality assurance procedures were hardly in effect. The circumferential joint was incomplete from inside creating a very weak and highly stressed v- notch formation on the weld.

This is apparently the obvious reason for the failure of the fillet weld under cyclic loading condition. (zero to 8 bar each day in 24 hr cycles). The v-notch was flexing in and out at each cycle of operation. This is very much analogues to a situation where we usually break a steel wire at a low tensional force but flexing several times.

7.13 Comparison of analysis of shell design with a material specified for the shell and with a material available in the Sri Lankan market

Considering SA **515/516 Gr 70** as the material specified,
From the calculation:

Required plate thickness = 7.03 mm;
Provided plate thickness = 10.00 mm;
Calculated pressure = 1.593 N/mm^2; and
Design pressure = 1.069 N/mm^2

Considering **A 36** as the material available in the market,
From the calculation:

Required plate thickness = 8.13 mm;
Provided plate thickness = 10.00 mm;
Calculated pressure = 1.283 N/mm^2; and
Design pressure = 1.069 N/mm^2

For the above two cases, since the design pressure is less than the calculated working pressure, provided thickness is adequate, respectively. However as of result of the calculation done under **3.1.1.a),** it was shown that according to the relevant ASME codes, since the design pressure is higher than the calculated working pressure, provided thickness is not adequate. Therefore, further it was observed that the ASME codes are more stringent compared to IBR.

Table 7.1 - Comparison between plate thickness using local material and IBR material

Grade of Steel Plate	**SA 515/516 Gr 70**	**A 36**
Required plate thickness, (mm)	7.03	8.13
Calculated pressure, (N/mm^2)	1.593	1.347

(When the Provided plate thickness is 10.00 mm at the design pressure of 1.069N/mm2)

7.14 Comparison of analysis of tube plate design with a material specified for the shell and with a material available in the Sri Lankan market

Considering **SA 515/516 Gr 70** as the material specified,

From the calculation:

Required plate thickness = 8.915 mm;

Provided plate thickness = 10.00 mm;

Calculated pressure = 1.593 N/mm^2; and

Design pressure = 1.069 N/mm^2

Considering **A 36** as the material available in the market,

From the calculation:

Required plate thickness = 8.910 mm;

Provided plate thickness = 10.00 mm;

Calculated pressure = 1.347N/mm^2; and

Design pressure = 1.069 N/mm^2

For the above two cases, since the design pressure is less than the calculated working pressure, provided thickness is adequate, respectively.

Table 7.2 - Comparison between plate thickness using local material and IBR material

Grade of Steel Plate	**SA 515/516 Gr 70**	**A 36**
Required plate thickness, (mm)	8.915	8.91
Calculated pressure, (N/mm^2)	1.593	1.347

(When the Provided plate thickness is 10.00 mm at the design pressure of 1.069N/mm^2)

7.15 Comparison of analysis of Manholes & Hand Holes door design with the material specified and with a material available in the Sri Lankan market

Considering **SA 515/516 Gr 70** as the material specified,

From the calculation:

Minimum calculated thickness of the flat door	=	27.43 mm
Provided plate thickness	=	28.00 mm
Working pressure of boiler	=	1.593 in N/mm^2
Design pressure	=	1.069 N/mm^2

Considering **A 36** as the material available in the market,

From the calculation:

Minimum calculated thickness of the flat door	=	26.04 mm
Provided plate thickness	=	28.00 mm
Working pressure of boiler	=	1.347 in N/mm^2
Design pressure	=	1.069 N/mm^2

For the above two cases, since the design pressure is less than the calculated working pressure, provided thickness is adequate, respectively.

Table 7.3 - Comparison between plate thickness using local material and IBR material

Grade of Steel Plate	**SA 515/516 Gr 70**	**A 36**
Required plate thickness, (mm)	27.43	26.04
Calculated pressure, (N/mm^2)	1.593	1.347

(When the provided plate thickness is 28.00 mm at the design pressure of 1.069N/mm^2)

7.16 Analysis of root-cause for the boiler explosions

In accordance with the information available in the Sri Lankan boiler industry, it is

revealed and quite evident that, most of the manufacturing plants do neither get the service of qualified welders nor qualified designers, as discussed in the Chapter 1.
To overcome these barriers, the manufacturers can be facilitated with tax concessions provided that the inspecting authority will assure the service provision of qualified welders and skilled designers. In addition to that, since there is no national guideline to be followed yet, proper design calculation is not carried out and as a result of that the

essential parameters such as thickness of the plates are being neglected. With the empowerment of law set with the standard as the baseline, this problem will be solved.

7.17 Cost analysis of imported boilers and locally manufactured boilers

In view of cost of locally manufactured boilers, no firm decision can be made due to the difficulties in revealing required information such as cost of employing qualified designers andwelders. However, considering an imported, Forbes Marshall oil fired steam boiler of two ton(2000 Kg/hr)and one will be able to get a rough idea as follows.

Total cost of the boiler	=	LKR 80, 00,000.00
FOB value of the boiler	=	LKR 74, 18,250.00
Therefore, total min. taxes	=	LKR 5, 81,750.00

This implies that the cost of the boiler can be reduced by at least LKR 5, 81, 750.00 if manufactured in Sri Lanka.

7.18 Alternative materials and their properties

Standards selected through the literature review, for the preparation of the adopted standard, mainly **ISO 16528 Part 1** and **IBR** specifies materials which have already been specified in ASTM standards. Mainly the material specified for shell, tube plate and man-hole door / hand hole; **SA 515/516 Gr 70** is very rare in the Sri Lankan market and the cost is very high too. For a small market such as in Sri Lanka this will be an unbearable burden. Therefore, it is not practicable, if the material requirements are restricted to such internationally specified materials only.

Hence, while the material specifications are being kept in line with the aforesaid ISO and IBR, an equivalent material has had to be introduced which is available commonly in the Sri Lankan market and also can be purchased for an affordable price. In search of such a material, a market survey was carried out. As the outcome of that market survey, in accordance with the Chapter 1 of this thesis, **A36** steel (plates)was selected as the most versatile material.

Mechanical and chemical properties of this material can be tabled as in

Table 7.4.

Table 7.4 - Physical, Mechanical and Chemical properties of ASTM A36[16] Steel plate

Physical Properties	**Metric**	**English**	**Comments**
Density	7.85 g/cc	0.284 Lb/in^3	Typical of ASTM Steel
Mechanical Properties	Metric	English	Comments
	400-550 MPa	58000 – 79800 psi	
Tensile Strength, Yield	250 MPa	36300 psi	
Elongation at Break	20 %	20%	In 200 mm
	23 %	23%	In 50 mm
Modulus of Elasticity	200 GPa	29000kpsi	
Bulk Modulus	160 GPa	23200 kpsi	Typical for steel
Poissons Ratio	0.26	0.26	
Shear Modulus	79.3 GPa	11500 kpsi	
Component Ele-ments Properties	**Metric**	**English**	**Comments**
Carbon, C	0.25 – 0.29 %	0.25 – 0.29 %	
Copper, Cu	0.20 %	0.20 %	
Iron, Fe	98 %	98%	
Manganese, Mn	1.03 %	1.03 %	
Phosphorous , P	<= 0.040 %	< = 0.040 %	
Silicon, Si	0.28 %	0.28 %	

Sulphur, S	< = 0.050	< = 0.050 %	

8 CONCLUSION AND FUTURE WORK

In this project an analysis of root cause of boiler explosions took place in Sri Lanka and a feasibility study for an adoption of available national standard specifications for the boilers as the remedy is carried out. Considering the Sri Lankan context of the boiler industry the adopted standard has to be developed with the assistance derived mainly from **Indian Boiler Regulations (IBR)** a publication of **Indian Republic** andslightly from **ISO 16528-1**, a publication of **International Organization for Standardization**.

The adopted standard will mainly specify design, manufacturing, inspection, testing and marking requirements for steam boilers and hot water boilers as of the scope, keeping in mind until a standard is stated as a part and parcel of the law of the particular country it is to be regarded as volunteer. Therefore, after the standard is enacted by the particular act passed in the parliament, in the implementation phase, based on a report prepared by an accredited testing body which will assess the design and construction, will report to the Labour Department of Sri Lanka, so that particular boiler can be granted the SLS mark.

Even though the material selected by a designer or a manufacturer is not a one which is specified in the standard, if it fulfil the requirements laid down in the standard with respect to inspection and testing, the Inspecting Engineer will have the sole authority to permit such a design for it to be proceeded with. For this research purpose it was chosen as **ASTM A 36** steel.

In case of testing, weld tests are of utmost importance. Specially the selected welder must have the required qualifications. All Non Destructive Test (NDT) inspectors shall possess minimum of **ISO Level-2** qualification in their respective fields or designated P1-F3 procedures by A. S. M. E. code.

A hydraulic pressure test shall also be carried out, at 150 percent of the design pressure and be maintained for a period not less than 30 minutes that shall be witnessed by the Inspecting Engineer. Boiler plates must also be inspected by the inspecting engineer while the manufacturer shall be responsible for obtaining relevant mill certificates from the manufacturer of plates.

Legible and indelible marking in accordance with the requirements laid down in Clause **2.8** of Chapter **2** is very essential in order to validate the manufacturing process and the boiler itself.

It must be emphasized that the laid down requirements are of minimum that shall be considered by the Inspecting Engineer and any other design exceeding those requirements will definitely be in safe side. Similarly, further it was observed that ASME is more stringent (clause 8.3) as a whole and exceeding the requirements. Analysis carried out in **Chapter 3** shows that any selected material available in the market can be checked for suitability using the given formulae. The required minimum thickness is the basic requirement to be fulfilled by any selected material.

Even after working on the material, this minimum thickness shall be maintained and alternatively there does not exist any other option for this. In addition to that each and every requirement with respect to testing shall be fulfilled.

Furthermore, analysis for the rest of the requirements laid down in IBR would be extended so that a comprehensive comparison could be carried out. Furthermore, studies can be extended up to even the manufacture of Thermic Heaters in Sri Lanka that can be considered as manufacture of pressure vessel too.

After the standard became mandatory through a legal process, Sri Lankan boiler industry will be regulated and liberalized so that the market opportunities are developed and enhance the operations by avoiding technical barriers to trade (TBT)

Also, it must be emphasized that this is a long felt need of the Sri Lankan industrial sector and specially of the Boiler manufacturing industry that involves preciseness that is an outcome of good metrological practices. Metrology is one of the four main pillars of the house of quality infrastructure of a country, rather an essential requirement to be fulfilled in order to gain a massive frog leap towards a sustainable development. Hence this approach would also be a forward march towards our historical sustainable development process enriched with universal concepts.

Finally, in view of feasibility of adopting an available standard as the national standard, since most of the required raw material are available in the market; the others can be made available; cost analysis shows favourable results and on the other hand the Department of Labour is in an urgent need to prescribe regulations under the national legislation on Factory Ordinance with respect to manufacture and safe operation of boilers, all the reasons are for the proposal.

Therefore in a nutshell, IBR is an adoptable standard as the national standard provided that a ‘national appendix’ where some special national requirements are contented. may be needed as an appendix.

REFERENCES

[1] Labour Department Statistics of Boiler Accidents

[2] Analysis of Boiler Explosions of Sri Lanka by the Labour Department of Sri Lanka

[3] Global Industrial Boiler Market Analysis by Technological advancement, Regional Outlook and Forecast to 2026

[4] Indian Boiler Regulations(IBR)

[5] SLS 1512: 2015 – Sri Lanka Standard Specification for Boilers

[6] ISO 16528-1:2007- Boilers and pressure vessels

[7] Welding Procedure Qualification of A36 Steel Using GTAW and GMAW by Brecken De Oilers, Neri Lupian, Regan Rumph and Prof. Victor Granados

[8] Boiler Failure Analysis by Unilever

[9] SLS ASTM A 105 - Specification for Carbon Steel Forgings for piping applications

[10] SLS ASTMA 106 -Specification for Seamless Carbon Steel Pipe for High-Temperature Service.

[11] SLS ASTM A 516 - Specification for Seamless Plates, Carbon Steel, for Moderate- and Lower -Temperature Service.

[12] SLS EN 10216 –Part 1 - Specification for Seamless Steel Tubes for Pressure Purposes – Technical Delivery Conditions – Non-alloy steel tubes with specified room temperature properties

[13] SLS EN 10216–Part 2 -Specification for Seamless Steel Tubes for Pressure Purposes – Technical Delivery Conditions – Non-alloy and alloy steel tubes with specified elevated temperature properties

[14] SLS EN 10217 – Part 1 - Specification for Welded Steel Tubes for Pressure Purposes – Technical Delivery Conditions - Non-alloy steel tubes with specified room temperature properties

[15] SLS EN 10217 –Part 2 - Specification for Welded Steel Tubes for Pressure Purposes – Technical Delivery Conditions - Non-alloy steel tubes with specified room temperature properties

[16] ASTM A 36 – Steel Alloys for Structural Steel.

[17] IS 2062 – Hot Rolled Medium and High Tensile Structural Steel –Specification (Seventh Revision) and Comparison Equivalent Chart

Appendix A INSPECTION FORMS[3]

FORM 1

Memorandum of Inspection

OR

Registration Book

Memorandum of Inspection Book shall be prepared for each Boiler.

The Inspection Engineer shall enter in ink all particulars and dimensions of the Boiler with the calculations for the various parts in details.

Page 1 of 2

PARTICULARS AND DIMENSIONS

Name of The Manufacturer	
Address of The Manufacturer	
T.No./ E. Mail Address	
Maker's Number	
Type And Description of Boiler	
Leading Dimensions	
Intended Working Pressure	
Place And Year of Make	

PARTICULARS AND DIMENSIONS OF CYLINDRICAL SHELL

EX: Length Between End Plates	
Thickness of Plates	
Details of Longitudinal Seams And Circumferential Seams	
Diameter of Shell	
No. of Belts Etc.	

PARTICULARS AND DIMENSIONS OF SHELL END PLATES AND STAYS.

PARTICULARS AND DIMENSIONS OF MAN HOLES, HAND HOLES, DOORS ETC.

PARTICULARS AND DIMENSIONS OF COMBUSTION CHAMBER / FURNACE, SMOKE / FIRE TUBES, WATER TUBES.

PARTICULARS AND DIMENSIONS OF MOUNTINGS AND FITTINGS, E.g.: SAFETY VALVES, PRESSURE GAUGES.

FORM 2

INSPECTING AUTHORITIES CERTIFICATE OF INSPECTION DURING CONSTRUCTION
[SLS Boiler Manufacturing –Chapter ....]

DESIGNATION OF INSPECTING AUTHORITY

We hereby certify that the .... type, boiler; length ....cm; diameter .... cm, working pressure .... bars . built by Messrs .... at ....under shop Number .... was constructed under our supervision and inspected at various stages of construction by the Inspecting Officer and that the construction and workmanship were satisfactory and in accordance with the Standard Conditions for the design and construction of land boilers under the SLS Boiler Manufacturing Regulations 2012.

The boiler is stamped on the front end plate/Shell Plate with our stamp as shown hereunder:-

MANUFACTURER'S NAME:	
WORKS NO :	YEAR OF MAKE:
TESTED TO :	ON:
W.P :	
INSPECTING AUTHORITY'S OFFICIAL STAMP:	

Hydraulic Test Results
The boiler on completion was / *The drum and headers were, subjected to a water pressure test of .... bar for period of ....minutes in the presence of the Inspecting Engineer on .... 20 .... and satisfactorily withstood the test.

*Samples of materials used in the constructions of the boiler were tested in the presence of the Inspecting Officer and found to comply with the requirements.

All welded seams were subjected to physical tests and radiographic examination wherever applicable and found satisfactory.

NOTE.- Strike off this paragraph where no such test has been carried out and the certificate in **Form 4** by a Well-known Maker is intended to be furnished.

We have satisfied ourselves that the construction and dimensions of the boiler are as shown in the Maker's Drawing No...........................signed by us, and that the particulars entered in the Maker's certificate of manufacture in **Form 3** countersigned by us are correct to the best of our knowledge and belief.

Signature of Inspecting Engineer   Signature of Inspecting Authority
Dated at ....this .... day of ....20... .
*Strike out what is not applicable

FORM 2-1

INSPECTING AUTHORITIES CERTIFICATE OF INSPECTION DURING ERECTION

DESIGNATION OF INSPECTING AUTHORITY

We hereby certify that the ……………… type, boiler; length ………………cm; diameter ……………… cm, working pressure ……………………………… bars built by Messrs ………………………………………………………………………… at ……………………………under shop Number ……………………. was erected under our supervision and inspected at various stages of erection by the Inspecting Engineer and that the erection and workmanship were satisfactory and in accordance with the Standard Conditions for the design and construction of land boilers under the SLS Boiler Manufacturing Regulations 2012.

All welded seams were subjected to post weld Heat treatment and Non –destructive examination wherever applicable and found satisfactory.

The Boiler on completion of erection was subjected to a water pressure tests of………………kg/cm ^{2} in the presence of the Inspecting Engineer on…………and satisfactorily withstood the test.
We have satisfied ourselves that the erection of the Boiler are as shown in the Maker's Drawing No: ……………………….are correct to the best of our knowledge and belief.

Signature of the Inspecting Engineer Signature of the Inspecting Authority

Dated at……………………….this……………………….day of……. 20…..

FORM 3

Manufacturer's Certificate of Form 3/1

Manufacture and Test

DESCRIPTION

1.1	Manufacturer's Name and Address	
1.2	Manufactured for	
1.3	Type Of Boiler	
1.4	Length Overall	
1.5	Diameter Inside Largest Belt	
1.6	Design Pressure	
1.7	Intended Working Pressure	
1.8	Shop Number Of Boiler	
1.9	Year Of Manufacture	
1.10	Total Heating Surface	
1.11	Final Temperature Of Steam (Design)	
1.12	Grate Area	
1.13	Brief Description Of Boiler	
1.14	Evaporation Capacity (For Calculation Of Relieving Capacity Of Safety Valves)	

Form 3/2

PARTS MANUFACTURED BY THE MANUFACTURER

2.1 Name ofThe Parts, Description, Leading Dimensions

Name Of Part(s)	Description	Leading Dimensions

2.2	Part(s) Manufactured – Inspected At All Stages Of Construction By	
2.3	Identification Marks	
2.4	Part(s) Hydraulically Tested And Internally Inspected After The Hydraulic Test By	

PARTS MANUFACTURED OUTSIDE THE BOILER MANUFACTURER

NAME OF PART(S)	DESCRIPTION	LEADING DIMENSIONS	MANUFACTURED BY	IDENTIFICATION MARKS	PART(S) MANUFACTURED INSPECTED AT ALL STAGES OF CONSTRUCTION BY	DESCRIPTION OF TEST CERTIFICATE (S)

Form 3/4

3.4 Shell Type Boilers of Welded Construction – The Construction is in Accordance with The SLBM Regulations

Number of Longitudinal Seams in Shell in Each Belt	
Number of Longitudinal Seams in Furnace	
Number of Circumferential Seams in Shell	
Number of Circumferential Seams In The Furnace	
Details of Repairs, If Any, Carried Out in Welded Seams During Construction	
Details of Heat Treatment	

All welded seams are subjected to radiographic examination to the satisfaction of the Inspecting Authority where required.

3.4 Fusion Welded and Seamless Forged Drums
Of Water Tube Boilers
The Construction Is in Accordance with The
Standard BoilerManufacturing Regulations

Number Of Longitudinal Seams In Each Ring	
Number Of Circumferential Seams	
Details Of Repairs, If Any, Carried Out To Seams During Construction	
Details Of Heat Treatment	

All Welded Seams Are Subjected To Radiographic Examination To The Satisfaction Of The Inspecting Authority where Required.

FORM 3/5

MATERIAL MANUFACTURE

PART NO.	BOILER PARTS & FITTINGS	MATERIAL	STEEL MAKING PROCESS	STEEL MAKER	REMARKS
	SHELL PLATE 1				
	SHELL PLATE 2				
	FURNACE P LATE				
	FRONT END PLATE				
	REAR END PLATE				
	TUBES				
	STAY TUBES				
	STAY BARS				
	MANHOLE PLATES				
	GUSSET				
	FLANGE (BLOW DOWN VALVE) ETC.				

Note: Under “Material” enter type of Steel

Under “Remarks” a brief explanation of process of manufacture, e.g. “Fusion Welding”

FORM 3/6

PART NO.	DESCRIPTION OF THE PART OF BOILER	THICKNESS OF PLATE-mm OR PIPE (DIA X THICKNESS)	TENSILE STRENGTH LIMITS kg/mm^2, MIN	ELONGATION PERCENTAGE LIMITS, MIN.	GAUGE LENGTH IN mm	MATERIAL STANDARD NUMBER
	SHELL PLATE BELT-1					
	SHELL PLATE BELT-2					
	FIRE EXPOSED PLATES					
	FURNACE PLATE RING 1					
	FURNACE PLATE RING 2					
	FURNACE PLATE RING 3 etc.					
	TUBES					
	SMOKE TUBES (PLAIN)					
	SMOKE TUBES (STAY)					
	WATER WALL TUBES					
	FRONT END PLATE					
	REAR END PLATE					

FORM 3/7

DETAILS OF DRUMS (WATER TUBE BOILERS)

No.	Description	Nominal Dia:	Length	Shell Plate		Tube Plate		Head			Man Holes No. & Size	Hydrostatic Test kg/cm^2
				Thickness mm	Inside Radius mm	Thickness mm	Inside Radius mm	Thickness mm	Type **	Radius of Dish mm		

** Head Type – Flat /Dished / Elliptical /Hemispherical

FORM 3/8

HEADERS AND BOXEX (WATER TUBE BOILERS)

Part Of Boiler	Size and-Shape	Thickness mm	Head Or End		Hydrostatic Test kgs/ cm^2
			Shape	Thickness mm	
Water Wall Headers 1					
2					
3					
4					
5					
6					

FORM 3/9

TUBES

S.No.	Description	Outside Diameter-mm	Thickness-mm	Manufacturer	Manufacturing Standard
1					
2					
3					
4					

FORM 3/10

MOUTINGS

S.No.	Description	Material	Type	No.	Size	Make
1	Main steam stop valve					
2	Auxiliary stop valves					
3	Safety valve – 1					
4	Safety valve – 2					
5	Safety valve – 3					
6	Blow down valve					
7	Air vent valve					
8	Feed water check valve					
9	Pressure gauge isolation valve					
10	Pressure switch isolation valve					
11	Automatic water level control valves					
12	Fusible plug					
13	Water level gauge					

FORM 3/11

DETAILS OF SAFETY VALVES AND TEST RESULTS

<table>
<tr><td>Manufacturer</td><td></td></tr>
<tr><td>Identification marks of the valves</td><td></td></tr>
<tr><td>Maker’s No.</td><td></td></tr>
<tr><td>Type</td><td></td></tr>
<tr><td>Lift – mm</td><td></td></tr>
<tr><td>Maximum design pressure</td><td></td></tr>
<tr><td>Adjustable pressure range</td><td></td></tr>
<tr><td>Capacity of the valve</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Valve details</td><td></td></tr>
<tr><td>Material</td><td></td></tr>
<tr><td>Valve seat</td><td></td></tr>
<tr><td>Flt / bevel</td><td></td></tr>
<tr><td>Diameter of valve seating</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Valve body</td><td></td></tr>
<tr><td>Material</td><td></td></tr>
<tr><td>Opening at inlet</td><td></td></tr>
<tr><td>Opening at outlet</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Springs</td><td></td></tr>
<tr><td>Material</td><td></td></tr>
<tr><td>Process of manufacture</td><td></td></tr>
<tr><td>Chemical composition</td><td><table><tr><td>C%</td><td>Mn%</td><td>Si%</td><td>S%</td><td>P%</td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table></td></tr>
<tr><td>Section of wire</td><td></td></tr>
<tr><td>Wire diameter –mm</td><td></td></tr>
<tr><td>Outside diameter of coil</td><td></td></tr>
<tr><td>Number of free coils</td><td></td></tr>
<tr><td>Free length of coils</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Test results</td><td></td></tr>
<tr><td>Place of test / Date</td><td></td></tr>
<tr><td>Blow off pressure</td><td></td></tr>
<tr><td>Closing down pressure</td><td></td></tr>
<tr><td>Does the valve chatter?</td><td></td></tr>
<tr><td>Does the valve seat leak?</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Is the test certificate attached?</td><td></td></tr>
</table>

FORM 3/12

CERTIFICATION

Certified that the particulars entered in Form 3-1, to Form 3-11, by us are correct and that parts and fittings in sections 2 to 11, against the names of which entries are made, have been used in the construction and fittings of the Boiler.

The particulars shown against the various parts used are in accordance with the en-closed certificates from the respective makers.

The design of the Boiler is that as shown in drawing No…………………………………………………………

The Boiler has been designed and constructed to comply with the SLSBM for a working pressure of ……………………….

At our named workshop and satisfactorily withstood a water test pressure of ………………………………………on the………. day of……………………in the presence of our responsible representative whose signature is appended here-under.

………………………….

…………………………. Maker

Name and signature of engineer (Signature of maker with name)

who witnessed the test designation

………………………………………

………………………………………

Name and signature of Name and signature of

Authorizedengineer inspecting authority

(1)

FORM IV

CERTIFICATES OF MANUFACTURING AND RESULTS OF TESTS IN LIEU OF FORM IV

It is hereby certified that Original steel maker's certificate in Form IV contain following information in respect of the

According to Drawing No:

Material used in the manufacture of the boiler or part thereof bearing maker's number

Part Of Boiler		Qty.	Charge/Heat No./ Plate No.	Steel Making Process	Specifications	Deoxidation	Name of Steel Mak-ers	Test Piece No.	Certificate No. & Date

Contd…

(2)

FORM IV

CERTIFICATES OF MANUFACTURING AND RESULTS OF TESTS IN LIEU OF FORM IV

It is hereby certified that Original steel maker's certificate in Form IV contain following information in respect of the

According to Drawing No:

material used in the manufacture of the boiler or part thereof bearing maker's number

Length / Breadth mm	O.D./ Thk mm	Heat Treatment	Chemical Analysis						Mechanical Properties Kg/mm^2		Elong % G.L. (mm)	Bend Test	Sr. No.	Remarks
			C%	S%	P%	Mn%	Si%	Al%	Y.S.	U.T.S.				

Appendix B HOT WATER BOILER PROCESS OUTLOOK DIAGRAM[3]

(Informative)