The Utilization of Low Carbon Steel as a Basic Material for Pressure Vessels: A Review

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Abstract. The selection of materials for making pressure vessels is still an important topic being studied today. Price factors, ease of processing, and reliability of the material are important things that need to be considered. On the other hand, accidents that occur in the industry due to errors in material selection and treatment of materials are the main causal factors. Low carbon steel has many advantages as the central material for pressure vessels, but it needs a more in-depth study to obtain comprehensive results. The purpose of the study was to analyze low carbon steel as the central material of pressure vessels. This research is a literature review research. This study examined the characteristics of low carbon steel and the types of treatments that can be done to become the central material of pressure vessels. The results of the study indicate that low carbon steel can be central material of pressure vessel. However, during the welding process of low carbon steel, there are changes in the properties of the material such as residual stress and hydrogen trapping in the welding. Alternative solutions that can be done are by preheating, post weld heat treatment (pwht), and coating on low carbon steel.

Keywords: preheating; pwht; coating.

1 Introduction

Pressure vessels are one of the important equipment in the oil, chemical, and fertilizer industries. The purpose of utilizing pressure vessels is to accommodate high-pressure liquids, air, gas, fuel, and others [1]. Important points that need to be considered in making pressure vessels are safety and reliability by considering the maximum pressure that can be supported by the pressure vessel so as not to cause significant damage [2]. Long-term use of pressure vessels has the risk of aging and material degradation caused by poor environments, high temperature changes, high pressure, radiation, and the impact of corrosion [3]. The impact is an increase in hardness and strength and decreased fracture toughness is the impact of pressure vessel fragility [4]. Excessive corrosion is the main cause of damage to pressure vessels because corrosion can form holes as the initial source of leakage [5]. Therefore, the selection

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of materials, connection techniques, to treatment before and after connection are important indicators in making pressure vessels.

Material selection is an important initial step in the manufacture of pressure vessels [6]. The selected material must meet good tensile strength, toughness, weldability, and good brittleness [7]. Materials that are often used as pressure vessels are usually low alloy steel with alloy elements of Cr 9%, Mo 1%, V 9%, and Ni 9% which have good corrosion resistance, high temperature strength, and toughness. Other materials are stainless steel, non-ferrous alloys, and non-metallic materials [8]. However, the use of this material certainly has high production costs.

One alternative material solution that can be used for the manufacture of pressure vessels is low carbon steel. The choice of low carbon steel in many uses in industry is due to several advantages of low carbon steel such as cheap purchase price, easy to obtain on the market, can be formed using many techniques, easy to weld, and easy to work with machining processes [9,10]. However, the use of low carbon steel as the central material for a pressure vessel requires further study to obtain the right set-up. Therefore, the study in this article focuses on the potential of low carbon steel as the central material for making pressure vessels through a literature study.

2 Methods

This type of research was a study by reviewing scientific sources from articles published in reputable journals and indexed proceedings. The steps of this method are (1) Planning a review; (2) Conducting a review; and (3) Reporting the review.

Planning a review
Planning a review refers to the problems that occur in the use of pressure vessels. Analyze the problem to the smallest unit of analysis that narrows down to the selection of effective and efficient materials for pressure vessels. Low carbon steel as the central material of the pressure vessel becomes the unit of analysis. The goal is to study the potential of Low carbon steel as the central material for pressure vessels. How does Low carbon steel become the central material for pressure vessels? What treatments need to be prepared for Low carbon steel as a pressure vessel?

Conducting a review
The literature sources selected as the main study material are publications from reputable international journals and trusted indexed international proceedings with a percentage reaching 95%. The articles reviewed amounted to 100 articles related to the study topic. Only 39 articles are related to the topic of study as the central material to answer the research questions.

Reporting the review

The results of the study are then interpreted to describe the answers to the research questions in the form of a report. The reporting is done explicitly with the main points related to the application of Low carbon steel as the central material for pressure vessels.

3 Results and Discussion

Results

Pressure vessel

Pressure vessels for high temperature applications such as boilers have thick walls because they are used for a long period of time. However, the materials used tend to be relatively expensive (X6) [11]. Pressure vessels have internal pressures greater than atmospheric pressure, so the design of pressure vessels is important to prevent leakage by selecting the right materials such as low carbon steel, aluminum alloy, gray cast iron, stainless steel, and titanium alloy (X7) [12]. Each material has different uses and functions such as (1) 20MnMoNi55 low carbon which is used for pressure vessels with low temperatures and higher strain rates; (2) Carbon fiber Composite which is used for Helium storage; (3) Nb-Ti micro-alloyed steels which are often applied for cryogenic temperatures; (4) Austenitic high-alloyed steels which are used for cryogenic temperatures and high pressures with thick walls; (5) Aluminum alloys are also used for cryogenic temperatures with more flexible properties and can absorb a lot of energy at low temperatures; (6) Inconel 718 is used for the oxygen vessels; and (7) Titanium alloy is used for the hydrogen vessel [6].

Pressure vessel design must compare physical properties, mechanical properties, and metallurgy as well as material cost and thickness. Several factors that are considered in the manufacture of pressure vessels are (1) fluid properties and chemical reactions; (2) service temperature; (3) material strength; (4) formability, weldability, and machinability, (5) corrosion resistance; (6) resistance to the external environment; (7) safety and life hazards; and (8) service life [8].

Low carbon steel

In addition to having good strength, weldability, and ductility properties, low carbon steel has the advantage of being relatively cheap, making it widely used in the manufacturing, gas, oil, mining, and geothermal industries. [13,14].

Material selection is an important thing in planning the construction of equipment. For pressure vessels or pressure vessels, the material characteristics that need to be met are materials that have good pressure and temperature resistance. Low carbon steel is a material with a main composition of iron (Fe) and carbon (C) with a content of less than 0.25% [15,16].

Discussion

Key factors in selecting pressure vessel materials are the availability of materials, fulfillment of application requirements, and corrosion resistance [17]. Pressure vessel materials may be brittle like cast iron or ductile like mild steel [18]. In this study, the study of pressure vessel manufacturing is limited to welding low carbon steel as the central material of pressure vessels with consideration of availability and strength requirements. The reason is, the welding area is a critical area in testing pressure vessel manufacturing results. Welding test results play an important role in steel inspection for pressure vessel applications [19].

Low carbon steel also has the ability to maintain strength even at very thin thicknesses, strong tensile capacity, shock and vibration resistance, and is easy to recycle [17]. However, low carbon steel has limited corrosion resistance and low yield strength and is usually not recommended for use in the creep range, namely for temperatures higher than 400°C [8]. In addition to having the advantage of being easy to form and weld, the weakness of low carbon steel which is easily corroded needs to be considered by coating low carbon steel with other elements such as Zinc [20]. The selection of zinc as a coating material is due to its low cost and easy application to complex and large components. The chemical composition of low carbon steel can be seen in Table 1.

Table 1. Chemical composition of low carbon steel [21].

Chemical composition of low carbon steel								
C	Si	Mn	P	S	Ni	Cr	Cu	Fe
0.17-0.2	0.17-0.37	0.35-0.65	≤0.035	≤0.035	≤0.3	≤0.25	≤0.25	Bal

Welding of low carbon steel for pressure vessel manufacture may cause cracks and residual stress. Therefore, welding of low carbon steel as the central material of pressure vessel needs to receive initial and final post-welding treatment. Pressure vessels are made with materials that have high thickness, causing the need for large welding volumes. As a result, the possibility of weld defects increases [22]. Welding of low carbon steel has a risk of structural changes due to the welding process at high temperatures [23]. The cooling rate plays a role in changing the properties of the material [24]. Changes in microstructure can improve the mechanical properties (hardness, strength, impact toughness and fatigue life) of low carbon steel [23,25]. This condition can be overcome by preheating and PWHT treatment. Preheating of the material and electrodes can reduce the width of the brittle zone and prevent crack formation [26]. Post weld heat treatment (PWHT) can provide lower hardness values and can reduce residual stress [27].

Failure of pressure vessels is caused by melting, buckling, creep, fatigue, fracture. Cracks can also be caused by material defects and can propagate into larger cracks [28]. Another problem that causes pressure vessel failure is the presence of residual stress [29]. Heat treatment can affect the microstructure and mechanical properties of the material [30].

Several factors that can be optimized to avoid brittle fracture are (1) low carbon content reduces brittleness; (2) cleanliness has an effect on the properties of steel where steel with low sulfur and phosphorus content has good toughness; (3) steel that is not given stress relief has lower toughness than that given; and (4) material welded with coarse grains has low toughness; and (5) thicker steel has low toughness when used for pressure vessels [31]. Cracks in welded joints can be caused by trapped hydrogen. Steel with high tensile strength absorbs more hydrogen, so it has a risk of cracking [32].

Preheating of steel at a temperature of 300-350oC can achieve optimum conditions in the sample [33]. The preheating temperature of 300°C produces maximum depth of penetration (DOP) and affects the evolution of the microstructure in the weld fusion zone [34].

Hydrogen tends to be trapped in the HAZ compared to the central material where the hydrogen affects the reduction of ductility and the occurrence of fractures in the microstructure. Control of heat input and rapid cooling are the main triggers, so appropriate PWHT is needed after welding [35].

Welding has the risk of residual stress and distortion due to the heating and cooling process which can have a negative impact on the mechanical properties of the weld area such as cracks. Mitigation of residual welding stress needs to be investigated further. Therefore, PWHT is considered necessary because it is predicted to reduce residual stress [36].

Welded joints are at risk of stress corrosion due to residual stress after welding which can be minimized by PWHT. PWHT has a greater effect on the base metal and HAZ at a temperature of 650oC where there is a decrease in hardness caused by the transformation of martensite to bainite [37]. In another case, Fe-2Cr-Mo-0.12C steel normalized at 930°C and tempered at 700°C has the best combination of ductility and strength. The optimal combination of strength and ductility can be obtained through tempering at a temperature of 700°C, which meets the needs of pressure vessels [38]. The addition of Mn (Manganese) content can refine the beam size and increase the number of grain boundaries which results in low crack propagation and increases the impact toughness of the steel [39].

4 Conclussion

Low carbon steel has the potential as the central material for pressure vessels because it has the advantages of being easy to form, easy to weld, and cheap and easily available in the market. Low carbon steel can be applied to pressure vessels that have low temperatures and higher strain rates. However, low carbon steel when welded has the risk of residual stress and hydrogen trapping. On the other hand, low carbon steel has a high risk of corrosion. Therefore, low carbon steel requires additional treatment such as preheating, post weld heat treatment, and coating.

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