The Development of Reinforcement Pad Design for Pressure Vessel

Al Emran Ismail, Mohd Zubir Mohd Ghazali

Abstract*: *This paper reviews research from difference researchers on pressure vessel component particularly reinforcement pad or repad design. Present study includes the history of pressure vessel and background of famous pressure vessel code American Society of Mechanical Engineers Boiler and Pressure Vessel Code establishment. Purpose of present research is to study the development repad design and the application repad on pressure vessels. Literatures from other researches on various repad design carried out by experimental and finite element analysis were discussed in present study.

Keywords: Reinforcement Pad, Repad, Nozzle, Intersection, Finite Element Analysis

I. INTRODUCTION

Pressure vessel is widely used in various application includes in petrochemical industries, power plants comprise of normal, critical and severe operational services. The design of pressure vessel was initiated in 1490s by Leonardo da Vinci as documented in his design book namely Codex Madrid I with the concept of pressurized air containers lifting the heavy weight underwater [1]. The pressure vessel and its components are carefully designed in order to reduce the risk of catastrophic failure that may result from unsafe application. There are lot of incidents occurred due to pressure vessel failures since the early of first industrial era in 1911s that pushed American Society of Mechanical Engineers (ASME) took the initiative to established guideline for design and manufacture pressure vessel. The first edition of pressure vessel code was developed 1914 which known as ASME Boiler and Pressure Vessel Code (BPVC). The design of pressure vessel and its components has been greatly improved since then. In pressure vessel, nozzle is one of critical part commonly used as apparatus connecting pressure vessel with the complete operation system. Nozzles carry load from external piping system and also sustain load from internal pressure.

The purpose of this paper is to review various design of reinforcement pad design on pressure vessel.

II. PREVIOUS LITERATURE FROM OTHERS

A. Failures on pressure vessels

In 1865, a boiler of Mississippi steamboat Sultana exploded seven miles from north of Memphis with 2,021 person onboard resulting in total destruction of vessel and loss of 1,450 lives. In 1894 another spectacular explosion occurred in which 27 boilers at coal mine in Pennsylvania destroyed entire facility at the cost of 6 lives and millions of dollar property damage. Pressure vessel and boiler continued to occur with unremitting frequency. Responding to the public interest to study the problem, in 1911 Council of ASME committee was appointed accordingly [2].

B. Governing code development

ASME BPVC widely used by designer or engineer as guideline to design, fabricate and testing new and old pressure vessel and boiler. Recent work by [1] has summarized common design and construction code used other than ASME BPVC such American Petroleum Institute (API) 510, British Standard Published Document (PD) 5500 and European Standard (EN) 13445-3. Work by other [3] also highlighted the adoption of ASME BPVC in several design of pressure vessel including the failure analysis, buckling design, limit pressure, plastic collapse and parametric finite element analysis (FEA) for burst pressure. Besides, the ASME BPVC includes guideline for designing each components inside the pressure vessel such as shell, nozzle, reinforcement pad, head, and openings. The ASME code had continued its development supported by Welding Research Council (WRC) which was founded in 1935 providing research in developing solutions to problems in welding and pressure vessel technology. WRC 107 [4] and WRC 207 [5] were published in 1965 are the most important bulletin adopted by ASME in providing guideline to determine local stress in pressure vessel shell section and local stress on pressure vessel nozzle respectively.

The most common adopted by most of researcher was ASME BPVC Section VIII which was regularly updated and maintained by the ASME committee.

C. Theoretical mechanism on stress and buckling

Gill has published his works on stress analysis of pressure vessels and pressure vessel components in 1970 [6]. Effort was made to study the main problems of structural analysis which arose in the design of metallic pressure vessels and components. Study has been conducted to analyze nozzle reaction in pressure vessel with detail elastic analysis on shell and stress concentration factor for nozzle in vessels under pressure, shear and moment loadings. In 1976, Kitching *et. al.* has studied effect of stress concentration factor (SCF) when repad installed in vicinity nozzle to shell junction area [7].

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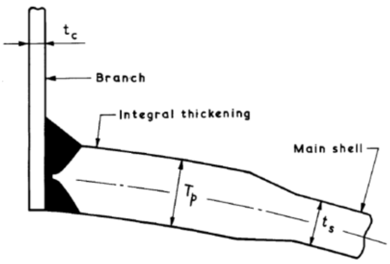
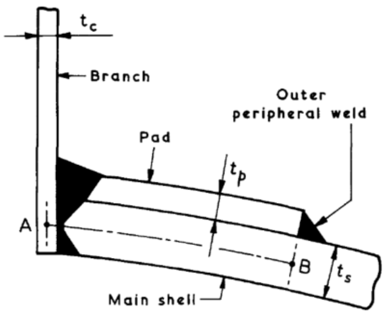
It was found that SCF reduced significantly when repad was used around nozzle to shell junction. The study concluded the used of repad found to be more economic design compared with the used of self-reinforced nozzle or integral type nozzle. The study was in agreement with previous research by Rodabough [5].

In 1987, Szyzkowski and Glockner have proposed buckle free design pressure vessel head subjected to internal pressure [8]. They concluded an effective method to reduce circumference membrane stress that possibly caused a buckling failure at head was by controlling depth of head dimension.

In 2017, Shi *et. al.* have studied effect of buckling analysis of cylindrical shell and at nozzle junction area [9]. They concluded that effect to local buckling at nozzle junction can be reduced by using repad at the nozzle junction area.



(a)



(b)

Fig. 1. Uses of additional material around nozzle area. (ab) Self reinforced shell and (b) repad at outside shell [7]

D. Repad design and development

Study in repad design has been recorded since 1970s by [7-8] and [12-13] performed parametric and numerical study while [10-11] performed experimental studies on various repad design. Beginning of 1990s, FEA has been used as tool to perform the analysis for repad at nozzle of pressure vessels [14].

E. Repad and its application

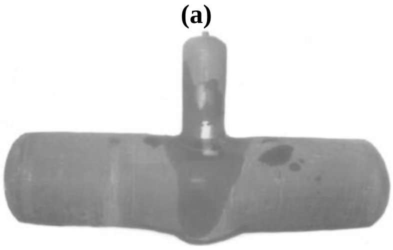
There are various method to design reinforcement pad or repad [15]. No distinction was made between the repad of vessel by locally increased shell thickness or by addition of repad welded on either inside or outside of the vessel. Repad mostly used at external side of shell opening in vicinity braches or junction in pressure vessels. Repad design subjected to internal pressure and limitation of uses was outlined in ASME BVPC [16]. The required total cross sectional area of reinforcement A, in any given plane through the opening for shell or head under internal pressure can be obtained from (1), where A is area reinforced required, d_r is diameter nozzle required, F is correction factor, t_n is nozzle wall thickness, t_r is required shell thickness and f_r is strength reduction factor.

$$A = d_r F + 2 t_n t_r F\left(1 - f_{r1}\right) \qquad (1)$$

F. FEM and experiment on repad by others

Earlier works by [10] had performed experiment on prototype pressure vessel with repad thickness of 14.3 mm carbon steel material installed outside the vessel. It was found that the used of repad had reduced the stress from internal pressure. Study by others [17] used 6 mm of carbon steel plate as repad for its vessel prototype for the experiment of influence of repad on limit and burst pressure at nozzle junction. They concluded that limit and burst pressure of vessel subjected to internal pressure was effectively increased by the use of repad. [18] Performed experiment on pressure vessel with 12.7 mm thick of carbon steel repad installed on the vessel to determine stress concentration factory (SCF) at the repad. The study successfully developed F factor to determine suitable SCF compared with previous method where SCF uniformly 1.0 used in designed the repad for all nozzle sizes.

(a)



(b)

Fig. 2. (a) Experiment by [17] carried out ruptured test on prototype vessel. (b) ruptured observed at nozzle shell junction area

In line with development technology in simulation and analysis, more sophisticated method tools has been made available for designer to design the pressure vessels and its components. FEA was used widely to perform analysis on pressure vessel parts particularly on repad design. Earlier work by [14] adopted FEA to analyze contact between shell and repad welded on the opening area.

[18, 19, 21, 22, 23, 24 and 25] performed FEA on repad and nozzle using various configuration of repad install outside of vessel shell.

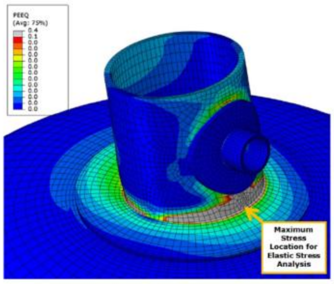


Fig. 3. FEA at nozzle to shell junction by others [26]

III. RESULT AND DISCUSSION

Design of pressure vessels and its critical component such as nozzle and repad continue to expand and developing. Although the ASME BVPC has provides guideline in designing the repad, latest study and research is necessity to continue in order to keep the pressure vessel design simplified without compromise its safety aspect. By understanding the function of repad, designer should be able to reduce time and resources in making selection or decide suitable type repad to be used. The use of FEA in repad analysis can improve user's understanding on repad behavior when the pressure vessel is subjected to any loading required by based on simulation cases.

IV. CONCLUSION

Study on repad designed has been recorded for a long time and the design development is on-going. Previous literature presented outcome studies on repad design which was performed numerically, experimentally and by FEA method with the repad configuration attached to external nozzle to shell junction area. Effort to study on repad design positioned inside the vessel is still exhausted and scarce.

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