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A Review Paper on Study of Pressure Vessel, Design and Analysis

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Abstract - *Pressure vessels are containers used to handle fluids which are highly toxic, compressible and which work at high pressures. Pressure vessels have applications in variety of industries such as Oil and Gas, Petroleum, Beverage industries, chemical industries, power generation industries, food industry, etc. Failure of pressure vessels has adverse effects on the surrounding and the industry which can cause loss of life, property and damages.*

The design of pressure vessel depends on factors such as pressure, temperature, material selected, corrosion, loadings, and many other parameters depending on the applications. This paper elaborates the work done in design of pressure vessels to reduce failures in the pressure vessels and study of the parameters such as material selection, operating pressure and temperature, design, analysis, etc. which cause fatigue failure or stress concentration in the vessels. The use of Finite Element Methods and Analysis techniques that provide results on failure in pressure vessels are to be studied. The future scope and advancements in pressure vessel design with software's is to be studied.

***Key Words*: Analysis, design, Finite Element Methods, failure modes, pressure vessels, software's.**

1.INTRODUCTION

A pressure vessel is a container having a pressure differential with respect to the atmosphere. The purpose of a pressure vessel is to store or process a high pressure high temperature fluid. The fluid can be toxic such as chemicals as well as non toxic such as steam. The pressure vessel has to be designed according to the standard available codes such as ASME (American Society of Mechanical Engineers) Section viii Division 1&2, EN/DIN (European) Code, IS (Indian Standard) Code. These codes have been designed by experimentation to obtain standards that fit to any application. Generally these codes are designed considering the factor of safety between 3 to 4.5. The design of pressure vessel is based on parameters such as pressure, temperature, corrosion, material selection, etc, the study of such parameters help in designing of the vessel. Variety of materials is available which are to be selected according to the application. The failure of pressure vessel can cause loss of life, property and damage to the system for which it is used. Hence the failures of pressure vessels are studied and methods are developed to avoid such failures .The stresses generated in the vessel are studied and determined using analytical procedures obtained from the codes as well as using software such as ANSYS, ABAQUS, PV Elite, Caesor, etc. Software such as PV Elite help to design and develop the vessels in less time and provide accurate results as per the code selected. Also care is taken that they work continuously for years without much maintenance.

2. LITERATURE REVIEW

The research papers related to the present work on pressure vessel are discussed and what conclusions were incurred are highlighted in this section.

Y.Q. Lu, H. Hui [1] have done investigation on mechanical behaviour of cold stretched and cryogenic stretched austenitic stainless steel to develop vessels with thinner shells. The experimentation included series of tests on S30403 steel plate by bringing it to temperature of 20̊ C at which cold stretching is done and at -196̊ C at which cryogenic stretching can be done. The martensite transformations, strength, plasticity properties exhibited by both the methods were compared. FEA based on MISO technique was used to simulate cold stretching and cryogenic stretching. It was observed that by cryogenic stretching the allowable stress of the material can be increased twice than that by cold stretching, promoting reduction in thickness of vessel by 60-75% resulting in light weight vessel.

Mr. Mukund Kavekar, Mr. Vinayak H.Khatawate, Mr. Gajendra V. Patil [2] have explained about use of composite materials to replace high strength to weight metals for use of pressure vessels in low weight applications such as aerospace and oil and gas. FRP laminates are used which consists of epoxy resins and E-glass fibre plies with suitable coatings. According to the analysis done using ANSYS they have compared steel and the composite for stress and weight. It is found that maximum stress in FRP composite was less than the allowable stress of FRP material. The structural efficiency of FRP vessel was more than steel vessel. Also weight reduction of 75% was obtained using FRP instead of steel simultaneously removing problem of corrosion of steel.

N.A. Weil, J.J. Murphy [3] have discussed factors determining performance of welded skirt support for vertical pressure vessels. The importance of thermal effects is emphasized. The performance of the vessel is assessed on fatigue basis by analysis of local stresses. During the work they found that special emphasis is to be given that the weld must be adequate to carry the weight of vessel, wind load along with discontinuity forces and moments. The thermal stresses are generated and their severity increases with temperature and vessel diameter roughly in the order $Ta^{0.5}$. The effect of the skirt/vessel thickness ratio, baffling, and insulation arrangements on thermal stresses is discussed, and mention is made of the improvements attainable by slotting the skirt. The assessment of fatigue performance is done in terms of maximum local stress range, number of cycles and fabrication quality. The initiation and propagation of crack in skirt welding is explained. Specific recommendations and suggestions for design and fabrication practices are given, including weld details for improved strength and quality. The lap-type attachment is indicated as the preferred choice for normal applications.

Siva Krishna Raparla, T.Seshaiah [4] in their paper have designed multi-layered high pressure vessel and compared it with monoblock vessel. Multilayered pressure vessels are built by wrapping a series of sheets over the core tube. Scope is obtained to select different materials at different layers according to functionality. Inner layer can be made of anti-corrosive materials while outer layers can be made of material having high strength. The design is based on ASME Code Section VIII division I. Using multi-layered pressure vessel results in percentage saving of material of 26.02% reducing overall weight of the vessel. With help of FEM software it is found that the stress variation from inner to outer surface for multilayerd vessel is 12.5% and that for solid vessel is 17.35% resulting in more uniform stress distribution. Thus the multi-layered pressure vessels are suited for high pressure and high temperature applications.

Puneet Deolia, Firoz A. Shaikh [5] have carried out Finite Element Analysis to estimate burst pressure of mild steel pressure vessel using Ramberg-Osgood model. Burst pressure is the pressure at which the vessel bursts or crack and fluid leaks which is undesirable and such pressure must not be exceeded. The burst pressure can be found out numerically using Ramberg-Osgood material curve. The finite element method is used to calculate the burst pressure using Ramberg-Osgood equation and then comparing it with the results obtained from elasto-plastic curve and true stress strain curve. Analysing the results Ramberg-Osgood model showed better correlation with the experimental observations as compared to modified Faupel Formula. Thus the use of FEM can help save time and cost of actual testing.

Sonachalam. M1, Ranjit Babu. B. G2 [6] have examined optimal ply orientations of symmetrical and asymmetrical shells for maximum burst pressure. Shells made of Glass Reinforced plastic with E-glass-epoxy-fibre. Specimen had 10 layers with different ply orientations. Finite Element Method is used to find the optimum winding angles. The test was done with layers oriented at [45°/45°/90°/45°] orientations. It was found that the maximum hoop stress developed for steel was 212.9 N/mm^2 applied pressure of 20MPa whereas stress for glass epoxy fibre reinforced plastic was 184 N/mm^2 for same applied pressure.

Simon Sedmaka, Mahdi Algoolb, Aleksandar Sedmakc, Uros Tatica, Emina Dzindoa [7] have studied the Elastic-plastic behaviour of welded joints during loading and unloading of pressure vessels. Pressurizing of the model was done in two stages. First the model was loaded to working pressure then held at a lower pressure for 2 hours. After unloading it was tested at total working load or water hammer load. They conclude that higher heat input to the weld zone is better. The HAZ of microalloyed steel has greater resistance to crack during load variations compared to WM. High stress levels for initiation of stable crack growth suggest the possibility that the welded structure can operate safely even in the presence of relatively large surface cracks. The integrity of heterogeneous welded joints is not affected by the presence of surface cracks because overmatching plays a protecting role, which consists in a small plastic deformation of weld metal even at high loads causing fracture of parent metal.

Andrade, Tatiana Lima, Paula, Wagner Andrade de, Junior, Pedro Américo Almeida Magalhães [8] have done a comparative study on methods to analyse stresses in vessel/nozzle due to external loads. A model of a nozzle without reinforcement is prepared so that comparison can be done by WRC 107, WRC 297 and FEA method. The WRC (Welding Research Council) Bulletin 107 is a parameterized procedure of stress calculation of nozzle in which the input values are dimensionless and the stress results are obtained from curves developed based on experimental data. WRC Bulletin 297 is a supplement to WRC 107 for higher diameter- thickness ratios. The stress values obtained by the three methods were close and are reliable for pressure vessels and nozzles that fit in WRC 107 and 297 procedure.

Apsara. C. Gedam, Dr. D. V. Bhope [9] have compared the stress distribution for different ends viz. hemispherical, flat circular, standard ellipsoidal and dished shape. The various dimensions of pressure vessel are obtained using analytical procedure. The model is prepared in Pro-E and analyzed using ANSYS. The analysis has been carried out for 2-D Axis-symmetric analysis, 3-D horizontal pressure vessel with saddle support and vertical pressure vessel over the stand. From analysis it is observed that the stress generated is less in dished end compared to flat or circular or hemispherical heads, so it is recommended to use ellipsoidal or dished head in vertical as well as horizontal pressure vessels. The arc length of saddle support does not have appreciable effect on stresses for horizontal pressure vessel and the length of leg support also have very marginal effect on stresses in vertical pressure vessel.

Dilip M. Patel1, Dr. Bimlesh Kumar2[10] have putforth an experimental method to analyse limit load on pressure vessel. Pressure vessels have openings and nozzle which create discontinuities and are centres for stress concentration. Hence pressure vessels have to be analysed using FEA to checkout how much stress is generated and is it in the safe limits before manufacturing the vessel. Distortion measurement test is done to measure the change in diameter of the vessel using pressurized water. Elastic slope method and tangent intersection method are used to find out load estimation of cylindrical vessel with oblique (45̊) nozzle. With help of FEA software interpreted results were found satisfactory and helped predicting the failure location of lateral connection. Evaluation of limit load is done by TIM & TESM test by load vs strain plot. Deformation occurs at the intersection area of the nozzle and the shell due to which shrinkage occurs in longitudinal section, Plasticity starts at acute side of nozzle and grows near around side towards obtuse side.

M. Jeyakumar a,*, T. Christopher[11] In this paper they have found out effect of residual stresses on failure of pressure vessel FEA has been carried out on 2D axis-symmetric model of material ASTM 36 carbon steel due to weld inclusions using ANSYS package. First an elasto-plastic analysis is performed on pressure vessel not having residual stresses. Then a thermo-mechanical finite element analysis is done to access residual stresses induced in the vessel during welding. Finally one more elasto-plastic analysis is done to see the effect of residual stresses on the pressure vessel. From the analysis it is observed that there is reduction in failure pressure due to unfavourable residual stresses.

Ahmed Ibrahim*, Yeong Ryu, Mir Saidpour [12] have discussed about stress developed in thin walled pressure vessels by doing a case study on a soda can by measuring the elastic strains of the surface of the can with help of strain gauges attached to the can. Generalized equations for stress and strain obtained by Hooke's law were used to find the longitudinal stress, hoop stress and internal pressure. The change in longitudinal strain and hoop strain were used to calculate the internal pressure in the can. Small variations were seen in internal pressures calculated form longitudinal strain and hoop strain.

B. F. Langer [13] in his paper Design of pressure vessels for low cycle fatigue has described methods for constructing a fatigue curve based on strain fatigue data used in pressure vessel design. When this curve is used the same strength reduction factor is to be used for both low cycle and high cycle fatigue. It is shown that the strain-fatigue curve can be estimated with fair accuracy and good conservatism when only the elastic modulus, the endurance limit, and the per cent reduction of area are known. The stress concentration factors are to be estimated to evaluate cycle life. Fatigue strength reduction factors have to be estimated rather than the theoretical stress concentration factors. When calculating the effects of combined mean and alternating stress, the fatigue strength reduction factor should be applied to both the mean and alternating component. These principles can be applied to any ductile metal subjected to limited number of load cycles.

Shyam R. Gupta, Ashish Desai [14] have designed a horizontal pressure vessel using PV Elite industrial software. For designing the vessel very few parameters such as design pressure, design temperature, inside diameter, volume, material, fluid properties, etc are required. PV Elite gives the thickness of the shell, head dimensions as per our selected head, nozzle calculations based on diameter given by us, loadings on pressure vessels, support design and calculations and all the parameters required to manufacture a pressure vessel. The stress generated in the vessel due to pressure loading and at discontinuities is obtained in the report from PV Elite. PV Elite does the calculations as per the code selected by the user and the stresses are calculated as per Welding Research Council (WRC) 107. The results obtained from the software are accurate and complying with the standard codes. Use of the software will help reduce design time and can give precise calculations and required data.

Abu Rayhan Md. Ali, Nidul Ch. Ghosh, and Tanvir-E-Alam [15] have discussed effect of autofrettage process in strain hardened thick walled pressure vessels. Equivalent von Mises stress is used as yield criterion to evaluate the optimum autofrettage pressure and the optimum radius of elastic-plastic junction. The ratio of outer radius to inner radius (b/a=k) value has effects on autofrettage and helps in deciding optimum autofrettage pressure with value of k. By studying the Von misses stresses, strain hardening, conclusions are developed. Autofrettage helps in moving the Vonmisses stress point from inner surface to outer surface. Because of autofrettage, percent reduction of maximum von mises stress increases for higher K value and for higher value of the slope of the strain hardening segment. Autofrettage helps to increase the pressure capacity of the pressure vessel by inducing residual compressive stresses at the inner surface.

Yogesh Borse and Avadesh K. Sharma [16] Basics of pressure vessel and its structure is explained. Stress Characteristics are mentioned in the paper. Finite element modeling and analysis done for different ends of pressure vessel. The different ends are Hemispherical, Ellipsoidal & Tori-spherical. Loads and boundary conditions for different ends are kept same and were found that hemispherical end have least stress.

V.N. Skopinsky and A.B. Smetankin [17] Stress analysis of nozzle connections in ellipsoidal heads and structural model is described. Finite element Analysis is done Timoshenko shell theory is used. Structural model of ellipsoid shell, numerical methods, special purpose SAIS program were discussed. Maximum effective stresses in between shell and cylinder were studied. Stress analysis of nozzle is discussed.

Sandeep Gond, Akhilesh , Anoop Singh , Vinod Sharma , Shyaam Bihari Lal[18] In this paper types of pressure vessel are studied. Design of pressure to show multilayer pressure vessels are suitable for high operating pressures than solid wall pressure vessels. A significant saving in weight of material may be made by use of a multilayer vessel in place of a solid wall vessel. Uniform stress distribution over the entire shell, which is the indication for most effective use of the material in the shell. Checking the suitability of using different materials for Liner shell and remaining layers for reducing the cost of the construction of the vessel. To verify the theoretical stress distribution caused by internal pressure at outside surface of the shell and to ascertain that the stresses do not reach yield point value during testing. Finally check the design parameters with FEM analysis by using ANSYS package to ascertain that FEM analysis is suitable for multilayer pressure vessel's analysis.

Prof. Vishal V. Saidpatil, Prof. Arun S. Thakare [19]. Design approach of pressure vessel are by ASME codes and Finite element analysis out of which analysis of Pressure vessel by FEA method is easy and get optimum parameters. Design calculation of FEA is compare with ASME boiler and pressure vessel regulations. In Comparison of the results and design parameters calculated by ASME boiler and pressure vessel code and finite element analysis are in thickness and reduces in weight of pressure vessel. Design by FEA is in weight reduction of pressure vessel.

M. Javed Hydera, M. Asifb [20] The main objective of this research work is to optimize the location and size of opening (hole) in a pressure vessel cylinder using ANSYS. Analysis is performed for three thick-walled cylinders with internal diameters 20, 25 and 30 cm having 30 cm height and wall thickness of 20 mm. It is observed that as the internal diameter of cylinder increases the Von Misses stress increases. Optimization of hole size is carried out by making holes having diameter of 4, 8, 10, 12, 14, 16 and 20 mm located at center in each of the three cylinders, and it is observed that initially Von Misses stress decreases and then become constant with hole size. The optimum size of hole is found to be 8 mm for cylinder having internal diameter of 20 cm whereas a hole of size 10 mm for cylinder having internal diameter of 25 cm and 30 cm on the basis of lowest Von Mises stress value. Lastly, optimization of location of hole is carried out by making a 12 mm hole located at 1/16, 1/8, 2/8, 3/8 and 4/8 of cylinder height from top in all the three cylinders. The Von Misses stress is maximum at the center i.e. 4/8 location and decreases in the direction away from center and then stress increases as the location is changed from 1/8 to 1/16 from cylinder top due to the end effects. The optimum location of the hole is found to be at 1/8 of cylinder height.

Peng-fei LIU, Ping XU, Shu-xin HAN, Jin-yang ZHENG [21] - As the idea of simulated annealing (SA) is introduced into the fitness function, an improved genetic algorithm (GA) is proposed to perform the optimal design of a pressure vessel which aims to attain the minimum weight under burst pressure constraint. The actual burst pressure is calculated using the arc-length and restart analysis in finite element analysis (FEA). A penalty function in the fitness function is proposed to deal with the constrained problem. The effects of the population size and the number of generations in the GA on the weight and burst pressure of the vessel are explored. The optimization results using the proposed GA are also compared with those using the simple GA and the conventional Monte Carlo method.

Amol Mali, S.A.Sonawane [22] have reviewed the effect of hybrid reinforcement on mechanical behaviour of aluminium metal composite. In their study of different papers they found that the stir casting method can be successfully used for manufacturing of Hybrid reinforced Aluminium metal matrix composite. The mechanical properties such as tensile strength, yield strength, hardness are more in the hybrid MMC than the simple aluminium composite. With the addition of materials such as silica, ash, alumina the reinforcement for the composite material can be increased resulting in better wear, corrosion, and mechanical properties due to better distribution of the hybrid materials in the Aluminium metal matrix.

Amol Mali, S.A.Sonawane, Sachin Dombale [23] have done a comparative experimentation on hybrid reinforced aluminium matrix composite with monolithic Aluminium Al356 to study the mechanical properties of both the materials. By carrying out the tensile test on UTM the results showed that the tensile strength of the hybrid reinforced Aluminium MMC is 12% more than AL356. The ductility of reinforced MMC reduces with increase in percentage of reinforcement and the compressive strength increases. Incorporation of ash increases the hardness of the Aluminium MMC upto some extent then decreases. The study shows that with the increase in percentage weight of ash and alumina content upto 12% the hardness of the composite can be increased.

A.S.Mali, P.S.Nalawade, S.B.Solepatil, S.S.Borchate, V.M.Bansode [24] focusing on the need of the industry for composite material over monolithic materials have done a case study on aluminium reinforced metal matrix composite. They have explained about the manufacturing of the aluminium alloy (LM25) with fly ash and alumina metal matrix composite using the stir casting method. The wear characteristics have been studied by using a pin on disc apparatus. Software MINITAB 16 was used to analyse the measured results. The experimental results were analysed using regression technique to find wear and coefficient of friction. From it results it was found that when the reinforcement is used the wear on the hybrid MMC (LM25 + Ash + Alumina) reduces comparably with the LM25 (non reinforced aluminium alloy. Hence the hybrid LM25 has better wear properties than the conventional LM25 composite.

Prof Mr.Aniket Kolekar, Mr.Akshay Natak , Mr.Kiran Navratne, Prof.Mr.Amol Mali [25] have studied about the Shape Memory Alloys and reviewed for the applications and advancements in this technology. The Shape Memory alloys are memory alloys which can retain their previous when subjected to the previous stimulus due to which they gained importance in certain applications such as aerospace, robotics, automobile, biomedical applications. The developments of the SMA's and their properties such as memory effect, super-elasticity have been studied. Factors required for selection of SMA are specified and the changes in such factors affecting the properties of the SMA's are studied. The recent advancement in SMA's such as improving material compositions, better design, better controller systems and fabrication processes have found wide commercial applications. Development of high temperature shape memory alloy, magnetic shape memory alloys, thin film SMA's, polymer SMA's have improved the performance of the applications. A lot of scope is available in future research and development of SMA's for a variety of applications.

3. CONCLUSIONS

This review paper provides information on various factors that help in understanding of factors affecting design, manufacturing and analysis of pressure vessel. Factors such as material selection have been studied along with the scope of composites in developing pressure vessels. Use of composites and pre-stressing methods can lead to development of light weight high pressure vessels for important applications. Design parameters such as selection of head help in reducing stress and uniform distribution of stress and load. Welding plays important role in manufacturing of pressure vessels and has to be studied for stress concentration or failure locations. Openings such as nozzles are to be carefully designed as they too act as stress concentrators and cause failure or leakage. Optimization and location, size of openings is suggested for high pressure vessels. Many finite element methods and analysis software are made available that do precise fatigue analysis of the vessels for failure in the design stage. Few of them are ANSYS, ABAQUS, Caesor, etc. Softwares such as PV Elite are helping a lot to save design time and cost by providing accurate results complying with the standards.

The use of hybrid reinforced Aluminium metal matrix which has better mechanical properties than simple composites can used for variety of applications. Smart memory alloys are being developed for special applications like biomedical, aerospace, robotics.

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