ABSTRACT Fatigue is not the most common cause of failures of pressure vessels, but designers should always take it into account due to the possible serious consequences of the failures of this type of structures and due to the fact that all pressure vessels experience some kind of fatigue loading which includes pressure fluctuations, mechanical and thermo mechanical loads.

In this work the fatigue assessment of a real size pressure vessel subjected to internal pressure fluctuations is carried out. The design of pressure vessel and evaluation of its fatigue life was done according to the rules provided in ASME boiler and pressure vessel code, section VIII, division 2. Fatigue life of designed pressure vessel was calculated by applying cyclic elastic-plastic finite element analysis. Strains and acoustic emissions were monitored during real time test. Different results obtained using the above stated procedure Designed and fabricated pressure vessel was tested experimentally. The cyclic elastic-plastic FEA proved very useful tool for predicting fatigue lives of critical areas of pressure vessel. Moreover experimental results were quite in favor of the numerical results. It was concluded that cyclic elastic-plastic FEA technique should be used in conjunction of ASME boiler and pressure vessel code, for the fatigue life evaluation of the pressure vessels especially those in which yielding of material may occur at some localized areas.

INTRODUCTION

The ASME boiler and pressure vessel code provides a fatigue evaluation procedure which is based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data is represented by the design fatigue strength curves. In these curves the alternating stress is plotted against the number of cycles. This stress is calculated on the assumption of elastic behavior but it does not represent a real stress when the elastic range is exceeded. The stress, on a gross scale, is elastic, but the metal deforms plastically at some localized areas. Such plastically deformed areas are constrained by the surrounding elastic material, thus the overall structural response remains elastic. However the plastically deformed regions are potential sites for crack initiation resulting in a finite life of a component. At higher stresses the fatigue life is progressively decreased, but the gross plastic deformation makes interpretation difficult in terms of stress. Fatigue design and fatigue related problems have been identified as a major area of
concern in a 1996 survey conducted by the newly formed European Pressure Equipment Research Council [1]. Chang T. Y worked on elastic-plastic deformation of cylindrical pressure vessels under cyclic pressure. He used a numerical procedure based on the finite element method and incremental solution approach for analyzing cylindrical pressure vessels deformed in the state of generalized plane strain [2]. This present task was performed using elastic-plastic finite element calculations applying submodeling techniques. This technique allows the structural details modelling using solid elements, applying boundary conditions imported from a global model based on shell elements.

**DESIGN AND FATIGUE EVALUATION BY ASME CODE**

Pressure vessel is designed according to the rules of ASME boiler and pressure vessel code, section VIII, division 2 [3]. Then the fatigue lives of individual parts of the pressure vessel are evaluated according to the mandatory appendix 5. Three main parts of the pressure vessel i.e shell, flat head and nozzle were fabricated separately and then the pressure vessel was tested under fatigue loading.

**Table.1 Designed Pressure Vessel Dimensions**

<table>
<thead>
<tr>
<th>Part of Vessel</th>
<th>Parameter</th>
<th>Calculated Value</th>
<th>Used Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>Thickness</td>
<td>3 mm</td>
<td>3 mm</td>
</tr>
<tr>
<td>Flat Head</td>
<td>Thickness</td>
<td>17.5 mm</td>
<td>17.5 mm</td>
</tr>
<tr>
<td></td>
<td>Radius of inner corner</td>
<td>9.5 mm</td>
<td>9.5 mm</td>
</tr>
<tr>
<td>Nozzle</td>
<td>Thickness of cylinder</td>
<td>0.67 mm</td>
<td>3 mm</td>
</tr>
<tr>
<td></td>
<td>Radius of inner corner</td>
<td>1 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td></td>
<td>Thickness of flange</td>
<td>6.38 mm</td>
<td>6.5 mm</td>
</tr>
</tbody>
</table>

**FATIGUE TEST DESCRIPTION**

The pressure vessel was subjected to an internal pressure fluctuation between 0 and 52.5 bars using water as hydraulic fluid. Each cycle has time duration of about 20 Seconds. For stress measurement, five bi-axial strain gauges were applied on different positions. In addition two acoustic sensors were also used for online monitoring of acoustic emissions during pressure fatigue test. The stresses observed were well below the material yield limit. High amplitude acoustic emissions were observed at about 5000 cycles. The amplitude of signals was raised in later cycles as shown in Figure 1. The high emissions indicate the crack initiation and growth. The test was continued for further cycles until we got highest amplitude about 100 dB.
FATIGUE EVALUATION BY ANSYS

ANSYS was used as the primary tool for obtaining cyclic elastic-plastic finite element solution of the current problem. The numerical stress analysis of the critical details identified in previous section was carried out using nonlinear finite element method. The S-N curve for the material “SA 516-G70” is corrected by data available in ASME code. The loading type considered is constant amplitude zero based. The appropriate stress concentration factors are also provided for correcting alternating stresses at such critical areas. Moreover the strain hardening parameters are also given to the software for evaluating plastic strains. The pressure vessels modeled and tested under the same condition as it was tested in actual. The pressure vessel was failed from inner corner of nozzle after 5051 cycles. This result is very close to the fatigue life analyzed by ANSYS.

COMPARISON OF RESULTS

The vessel used in this research work was designed for a life of 4500 cycles. The fatigue life analyzed by ANSYS is 5234 whereas experimental results showed an actual life of 5051 pressure cycles. The FEA and experimental results are very close to each other as shown in Figure 2. Experimental stress analysis results are also similar to the FEA results. The stresses evaluated by both techniques are very close to each other in all three main regions of pressure vessel as shown in Figure 3. Cyclic elastic-plastic FEA results showed that the nozzle inner corner is the weakest area from fatigue point of view. These FEA results are also validated experimentally because vessel was failed from same inner corner of nozzle.

CONCLUSIONS

ASME-BPV code, although conservative, cannot evaluate the exact fatigue life of a pressure vessel because; it provides the fatigue evaluation procedure for individual parts of a pressure vessel and not for a assembled pressure vessel. Whereas the cyclic elastic-plastic FEA proved very useful to predict the overall fatigue life of a such pressure vessels. The slight difference in experimental and numerical results occurred because of some manufacturing laps, software limitations and short duration of pressure cycles. Shift in the experimental and numerical results
is there but the overall behavior seems to be identical. The elastic-plastic state of stress is observed at nozzle inner corner in this case. It proves that although well designed pressure vessel could have some localized areas where yielding may occur. It is recommended for design engineers to evaluate such areas by FEA to save time and fabrication cost. Acoustic emission monitoring during hydrostatic and cyclic pressure testing proved very useful to judge the crack initiation and crack propagation phases of tested pressure vessel. Through FEA, we can minimize the total design and analysis time. Moreover complex and stress concentrated areas of pressure vessel can be evaluated quickly and accurately.

![Fatigue Life of Pressure Vessel](image)

**Figure.2** Fatigue life of Pressure Vessel

![Stresses in Pressure Vessel](image)

**Figure.3** Stresses in Pressure Vessel

MED UET Taxila (2007)
REFERENCES

