CHAPTER 6
SUMMARY, CONCLUSIONS AND FUTURE DEVELOPMENT

6.1 Summary

The present work encompasses the following objectives.

- Evaluation of the flexural response of symmetric and anti-symmetric composite laminated plates using higher order ESL models and layer wise model,
- Extend these models for buckling studies,
- To develop displacement based ESL model for flexural response and stability study of FG Plates.

Three higher order models were assessed for bending and stress analysis of laminated composite plate. Static response is studied in detail using two displacement based ESL models in which ZSDT uses shear stress resultants and the HSDT uses higher order rotations to incorporate the effects of transverse shear deformation. Since these models cannot represent shear stress continuity at the interfaces and zig-zag nature of the displacement field, a layer wise model is also evaluated. In all these models traction free boundary condition is enforced at the plate faces and no shear correction factors are needed. Based on the results it is concluded that the layer wise laminate theories prove to be the best alternative to 3D theories. They yield solutions close to the 3D elasticity theory for deflection and stresses. ESL model also predicted
high accurate results for both thick and thin laminates. CLPT underestimates deflections and stresses.

To achieve a reliable and safe design, accurate prediction of stresses and displacements are essential and the stresses generated due to loads should be below the allowable stresses for the materials used. In practice, a plate structure may be subjected to in-plane loads or transverse loads or both acting simultaneously and hence has to be designed for strength as well as stability. The ZSDT has been extended for studying the buckling behaviour. The Layer Wise Model is also used for investigating the buckling response and a comparative study is done. The present work discusses the effect of side to thickness ratio, aspect ratio, modular ratio and number of layers on the non-dimensionalised buckling loads due to uniaxial and biaxial loading. The numerical results show that for thick laminates the effect of transverse deformation is highly essential when the material exhibits high orthotropic ratio or when the number of layers is more. CLPT results are independent of the side to thickness ratios and overpredict the buckling loads for thick and moderately thick plates. In general, it can be concluded that the ESL theories are adequate in representing global responses such as deflections and buckling loads, but inadequate in representing local effects such as stresses at the ply level with a similar level of accuracy when compared with Layer wise models.

In recent years, FGMs have gained considerable attention in many engineering applications. The spatially variable material properties make FGMs challenging to analyse and accurate estimation of effective properties of FGMs is the key to the eventual success on the design. Here, a computational model using Zeroth order Shear Deformation Theory (ZSDT) is developed for the flexural and buckling analysis of FG plates. A macroscopic approach according to a power law distribution in terms of the
volume fractions of the constituents is adopted for the material property gradation in the thickness direction. Non dimensional stresses, displacements, buckling loads are computed for plates with ceramic metal mixture. ZSDT can predict highly accurate results for both thick and thin FG plates. The higher order effects are taken into account keeping the complexity to a considerably lower level. The ZSDT has same number of unknown variables as that of the Reddy's higher order model and is able to estimate the deflection, stresses and buckling loads to a similar level of accuracy. Hence, this approach appears to be a new addition to the plate theories for analysis of FG plates. Results obtained for FG plates should serve as bench mark results for future comparisons.

6.2 Conclusions

Following conclusions are drawn from the present research work

- The ZSDT model presented in this research can be used to describe the static responses and buckling loads for both thick and thin plates accurately which is substantiated by the numerical results presented in this thesis. In this model, the higher order effects are taken into account keeping the complexity to a considerably lower level.

- In the comparative study for stress analysis with HSDT and LWM, it is seen that layer wise theories prove to be the best alternative to 3D Elasticity theories.

- In the study of FG plates for stress and buckling analysis, ZSDT provides results in excellent agreement with available solutions
The UNSDT which does not enforce traction free boundary conditions at top and bottom of plate faces, slightly overpredicts the buckling loads for FG plates when compared with other higher order models. Thus, based on the study, the model based on ZSDT is highly recommended for reliable analysis and design of advanced composite structures which includes laminated and functionally graded plates.

6.3 Scope for Future Work

1. The structural elements of certain advanced engineering structures are subjected to intense thermal input. Analysis of composite laminates subjected to temperature gradient besides mechanical loading can be carried out by extension of ZSDT and layerwise model to include thermo elastic effect. Investigations can be carried out to understand the buckling behaviour under thermal loadings using these models.

2. The influence of shear buckling on the dynamic responses has to be investigated.

3. The ZSDT may be extended for non linear flexural analysis of laminated composite plates and FG Plates by incorporating strains in the Von-Karman sense. This model may be investigated for non linear stability studies.

4. ZSDT model could be used to develop a finite element approach to study the large deformation problems including the geometrical non linearity.

5. FGMs are projected as thermal barrier materials. Quite naturally, the study of the material response under such intense temperature loading is essential. ZSDT may be used for thermo mechanical modelling of the solids made of FGM.
6. For analysis of FG plates, various homogenisation schemes using micromechanics approach such as Mori Tanaka Scheme / Self Consistent Schemes could be used for finding the effective material properties. Most of the nature’s material forms are non homogeneous with functionally graded material structure. By applying the many possibilities inherent in the FGM concept, it is anticipated that materials will be improved and new functions for them created. It would not be too much to hope for, in the near future, materials whose constitution can be sufficiently controlled to meet our functional requirements.