INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY SCIENCES AND ENGINEERING, VOL. 2, NO. 5, AUGUST 2011

Wrinkling in Aluminum Sheet under Bi-Axial Loading using Finite Element Analysis

Jawad Ahmed Jadoon[1] **and Irfan A. Manarvi**[2]
[1,2]Department of Mechanical Engineering, HITEC University Taxila, Pakistan

Abstract– **Aluminum is becoming the most popular metal in a wide variety of applications in manufacturing of components for airplanes, automobiles, house hold etc. A wide variety of parts are manufactured using aluminum sheet of different alloy composition. Wrinkling of sheet metal is the most undesirable phenomenon in sheet metal forming, drawing, punching and other similar manufacturing processes. The current research is focused on Finite Element Analysis of Aluminum sheet to simulate onset and extent of wrinkling in aluminum sheet, using FE software ANSYS. Based on the results a comparison was drawn between the wrinkling behaviors at varying load values and points of application.**

Keywords– Wrinkling, Finite Element and Aluminum Sheet

I. INTRODUCTION

Wrinkling is an undesirable phenomenon in forming sheet metal components and parts. It creates difficulty in final part assembly and affects their functioning as well as appearance; moreover, it may cause damage to the surfaces of costly dies. Therefore, the prediction and prevention of wrinkling has always remained of paramount importance in sheet metal forming.

Research on the prediction of wrinkling has been made for the past many decades using both analytical and numerical methods. Prediction of side-wall wrinkling in sheet metal forming processes of the region undergoing circumferential compression based on simplified flat or curved sheet models with approximate boundary conditions and comparisons with experimental results of the Yoshida buckling test, aluminum square cup forming and aluminum conical cup forming was presented by Xi Wang and Jian Cao [1]. J Hematian and P M Wild investigated the effect of initial imperfections on the initiation of wrinkling in finite element models of deep drawing operations, using models of an annular plate subjected to radial in-plane loading and the effects of different types, magnitudes and distributions of imperfections [2].

Finite element (elastic-plastic) analysis of sheet metal forming process using the finite element software, LUSAS simulation was carried out by Hakim S. Sultan Aljibori and Abdel Magid Hamouda [3]. Finite element simulation of strain localization with large deformation, capturing strong discontinuity using a Petrov–Galerkin multiscale formulation, was done by Ronaldo I. Borja [4]. A. Selman et al carried out adaptive numerical analysis of wrinkling in sheet metal forming, using a comprehensive approach to wrinkling prediction and proposed a new wrinkling indicator that can be used in the contact areas during forming [5].

This research is focused on Finite Element Analysis of thin Aluminum sheet of the shape of Yoshida specimen with thickness 0.2 mm subjected to tension in a diagonal direction (Yoshida buckling test) to simulate onset and extent of wrinkling at different load applications using ANSYS software.

II. METHODOLOGY

Material Selection: For the current analysis, Aluminum 6061-T6 was chosen, having following physical and mechanical properties:-

a. Density	2.7g/cc
b. Hardness, Brinell	95
c. Hardness, Knoop	120
d. Ultimate Tensile Strength	310 MPa
e. Tensile Yield strength	276 MPa
f. Modulus of elasticity	68.9 GPa
g. Poisson Ratio	0.33

Model Preparation: Yoshida buckling sample was modeled in ANSYS with the dimensions as shown in Fig 1.

Load Application (Unidirectional): The model was constrained for zero displacement in all degrees of freedom along AA' (Fig. 1(a)). Analysis was carried out by applying following loads along BB' (Fig 1(a)), corresponding to the Tensile Yield Strength of the material:

a. 2263 N corresponding to Yield strength
b. 2489.3 N corresponding to YS+10% YS
c. 2036.7 N corresponding to YS -10% YS

For the Finite Element analysis, element type brick 8 node 45 was chosen, which is a 3D element and used for analysis for displacement, stress, strain and creep in the co-ordinate axis X, Y and Z. The model was then meshed using ANSYS software tool.

After assigning the required inputs i.e., material properties, element type and displacement constraint, loads were applied to the model and solution was run.

Load Application (Bidirectional): In next step same loads were applied simultaneously in X as well as Y directions along the diagonals of the sample (Fig. 1(b)). Solution was run in the similar manner.

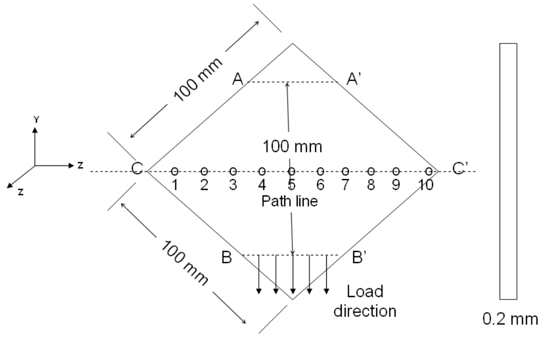

Fig. 1(a). Yoshida Buckling Sample (Unidirectional Load)

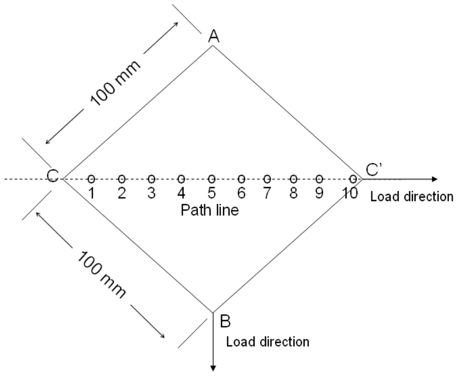

Fig. 1(b). Yoshida Buckling Sample (Bidirectional Load)

III. RESULTS

Nodal Displacement and Corresponding Stress Distribution: Results of nodal displacements and stress distribution along the path CC' (as shown in Fig. 1(a)) in X,Y, Z axis of the specimen, against different load applications were obtained from the solution, which are shown in succeeding figures. These values indicate relative movement and stress distribution in different axis. From this data we can predict the extent of wrinkling in the sheet at different loads. Fig. 2(a) – Fig. 2(f) show results for 2263 N load.

The nodes to the left of the specimen centre are displaced in positive X direction along the path, whereas, the nodes to the right of the centre are displaced in the negative X direction. It indicates that the specimen is compressed diagonally towards the centre. This is confirmed from the stress graph where negative values indicate compressive stress. The maximum value of stress is at the centre of the specimen.

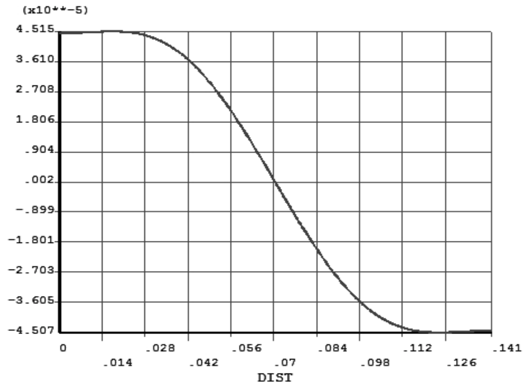

Fig. 2(a). Displacement in X-axis (m)

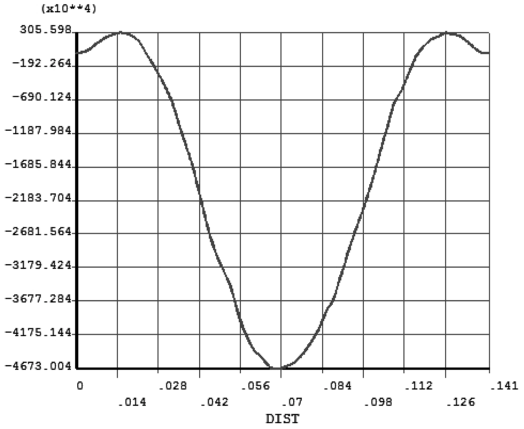

Fig. 2(b). Stress in X-axis (Pa)

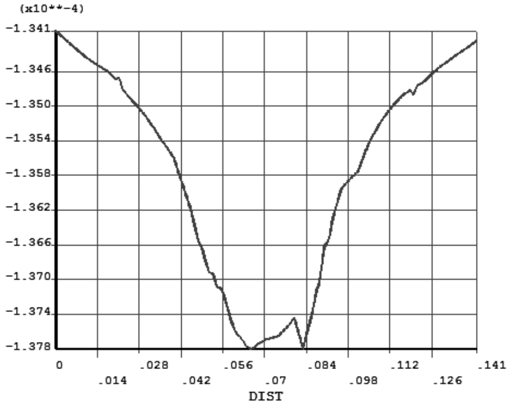

Fig. 2(c). Displacement in Y-axis (m)

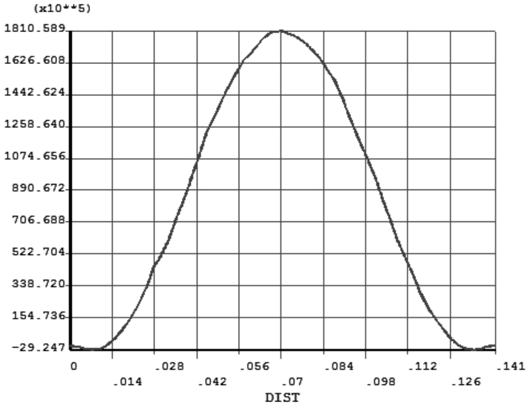

Fig. 2(d). Stress in Y-axis (Pa)

The nodes are displaced in negative Y direction along the path and maximum displacement occurred around centre of the specimen. It indicates that the specimen is stretched vertically downwards in the direction of applied load and experience tension in Y direction. This is confirmed from the stress graph where positive values indicate tensile stress. The maximum value of stress is at the centre of the specimen.

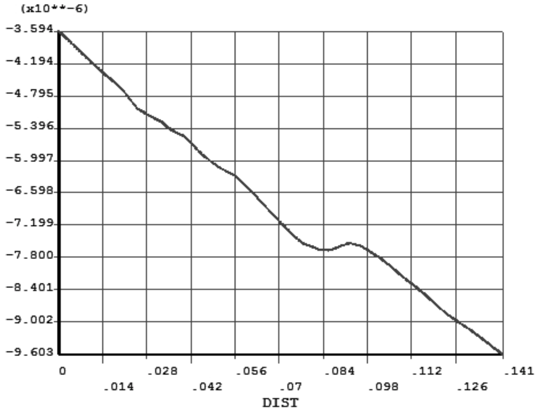

Fig. 2(e). Displacement in Z-axis (m)

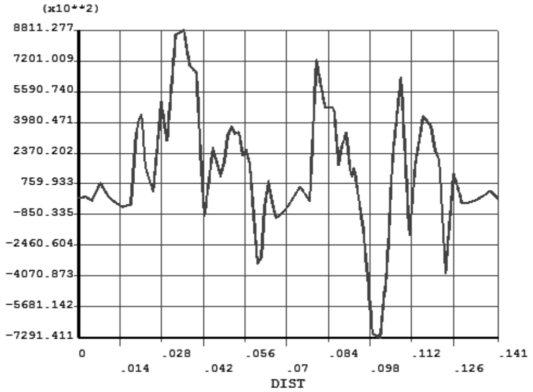

Fig. 2(f). Stress in Z-axis (Pa)

The nodes are displaced in negative Z direction along the path. A pronounced variation in the displacement curve indicates wrinkling around centre of the specimen. Variation of stress between negative and positive values indicates simultaneous compression and tension along the path line in Z direction. This variation causes wrinkling in the specimen. The wrinkling is more pronounced on the portion of specimen, which lies directly under applied load and the extremities are less wrinkled.

The nodal displacements and stress distribution exhibit similar behavior at different loads. Only the extent of displacement and stress varies against applied load. Fig. 3(a) – Fig. 3(f) show results for 2489.3 N load.

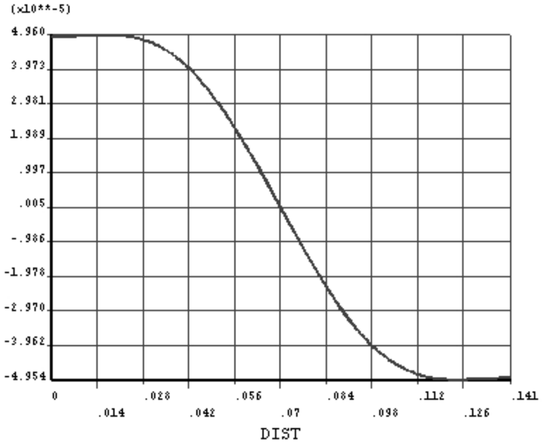

Fig. 3(a). Displacement in X-axis (m)

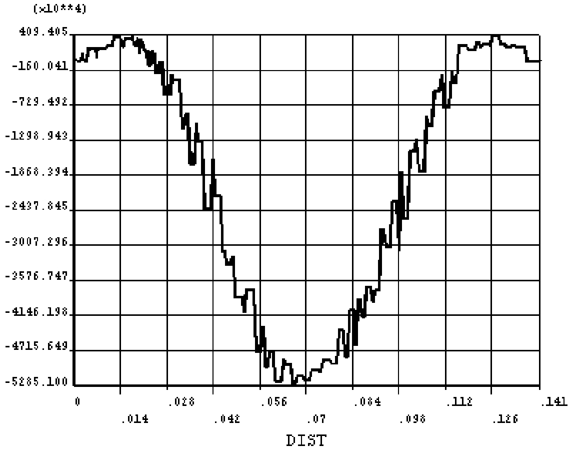

Fig. 3(b). Stress in X-axis (Pa)

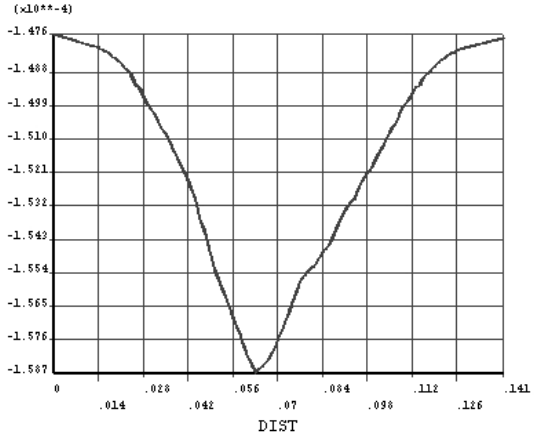

Fig. 3(c). Displacement in Y-axis (m)

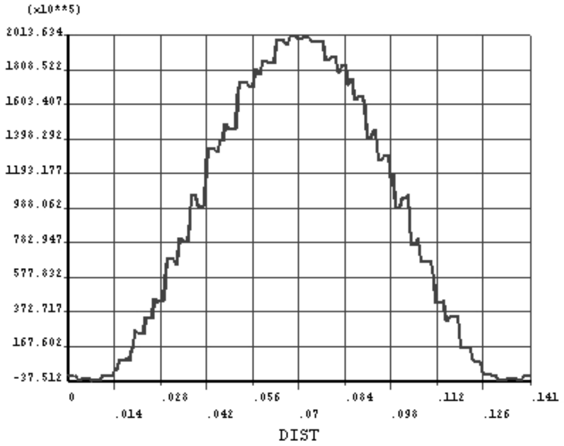

Fig. 3(d). Stress in Y-axis (Pa)

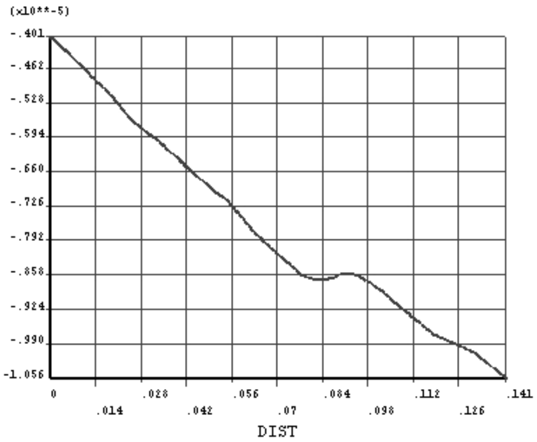

Fig. 3(e). Displacement in Z-axis (m)

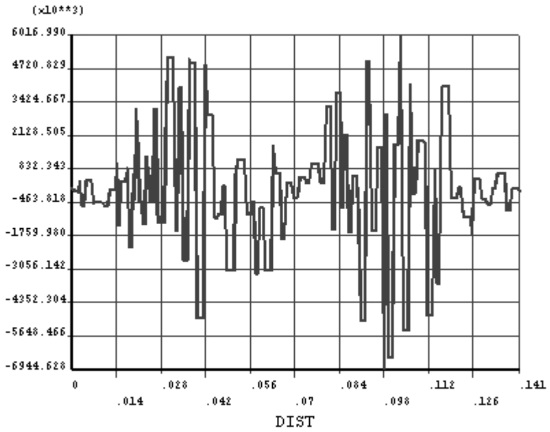

Fig. 3(f). Stress in Z-axis (Pa)

Results of displacement and stress distribution for 2036.7 N load are shown in Fig. 4(a) – Fig. 4(f).

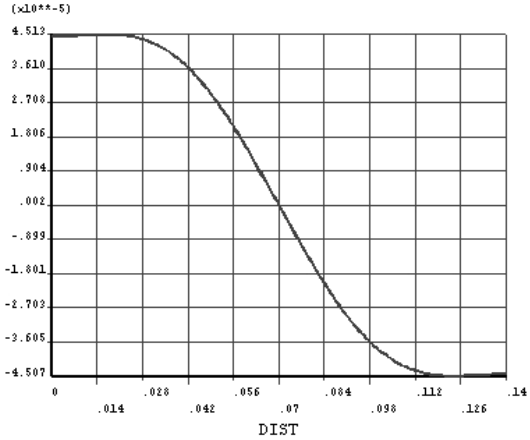

Fig. 4(a). Displacement in X-axis (m)

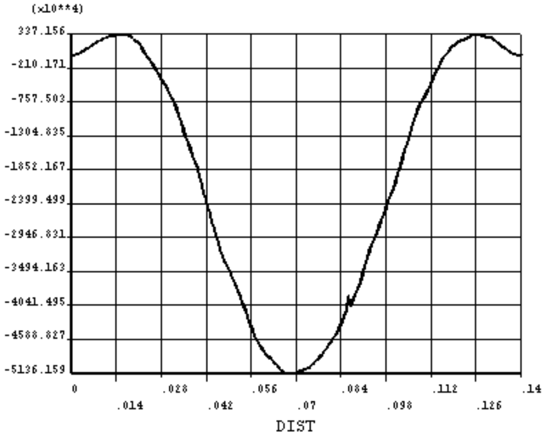

Fig. 4(b). Stress in X-axis (Pa)

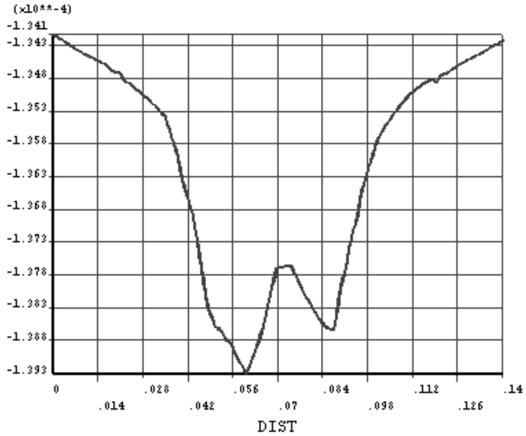

Fig.4(c). Displacement in Y-axis (m)

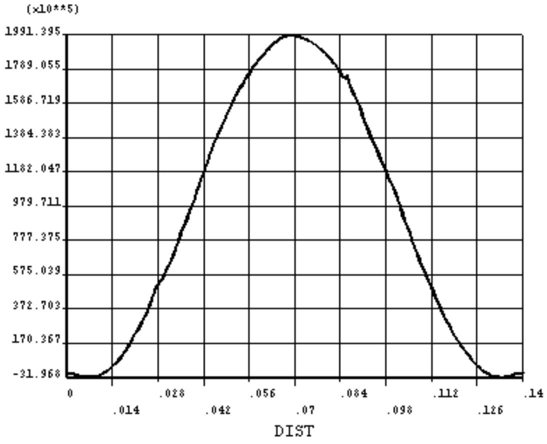

Fig. 4(d). Stress in Y-axis (Pa)

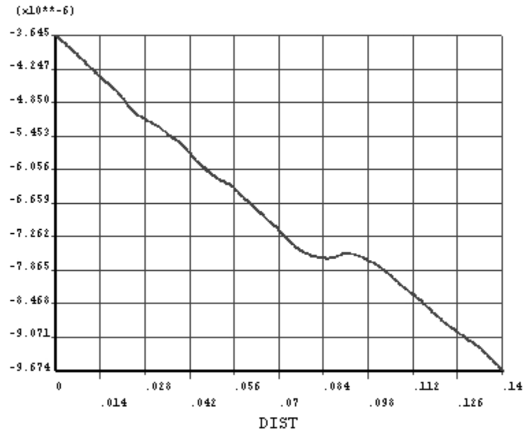

Fig. 4(e). Displacement in Z-axis (m)

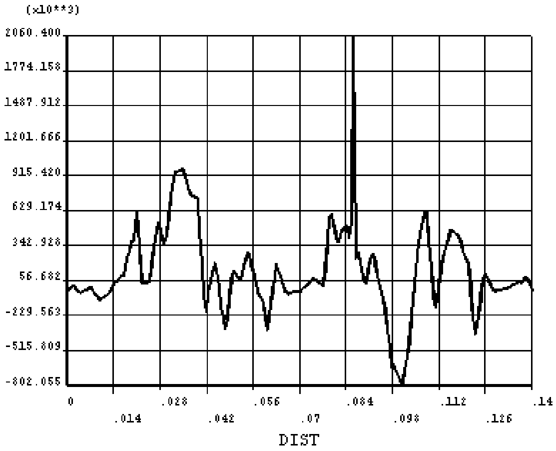

Fig. 4(f). Stress in Z-axis (Pa)

Nodal Displacement And Corresponding Stress Distribution: Results of nodal displacements and stress distribution along the path CC' (as shown in Fig. 1(b)) in X,Y, Z axis of the specimen, against different load applications were obtained from the solution, which are shown in succeeding figures. These values indicate relative movement and stress distribution in different axis. From this data we can predict the extent of wrinkling in the sheet at different loads. Fig. 5(a) – Fig. 5(f) show results for 2263 N load.

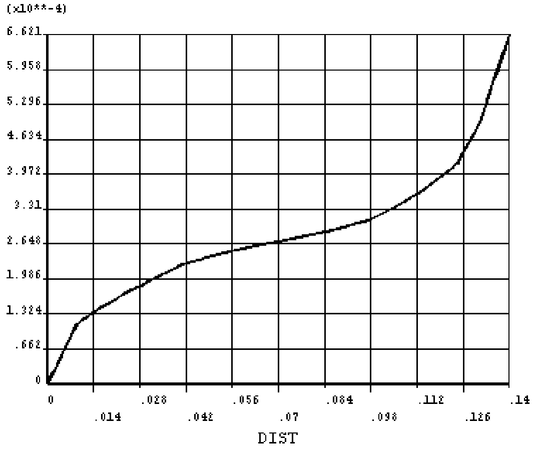

Fig. 5(a). Displacement in X-axis (m)

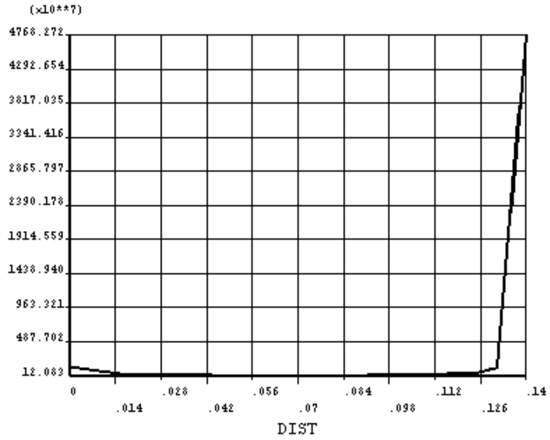

Fig. 5(b). Stress in X-axis (Pa)

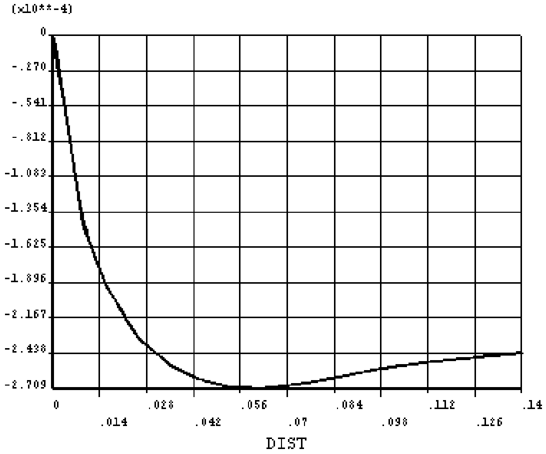

Fig. 5(c). Displacement in Y-axis (m)

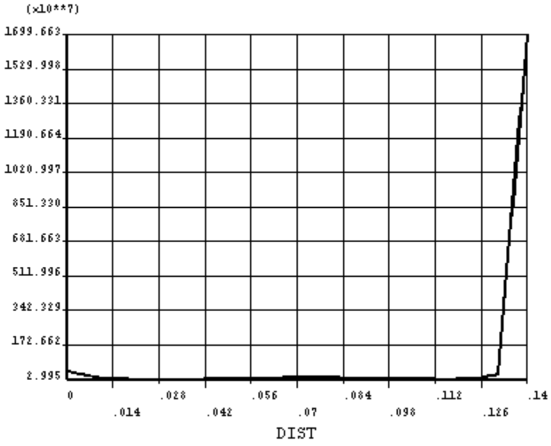

Fig. 5(d). Stress in Y-axis (Pa)

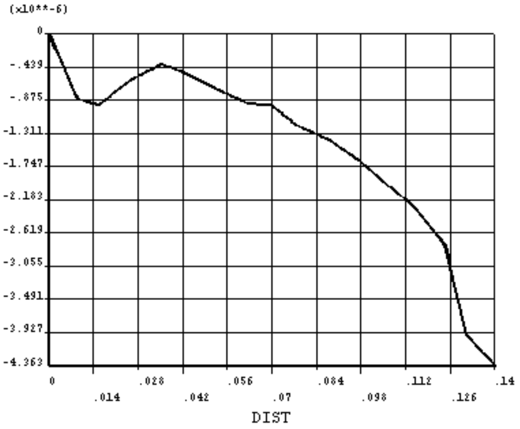

Fig. 5(e). Displacement in Z-axis (m)

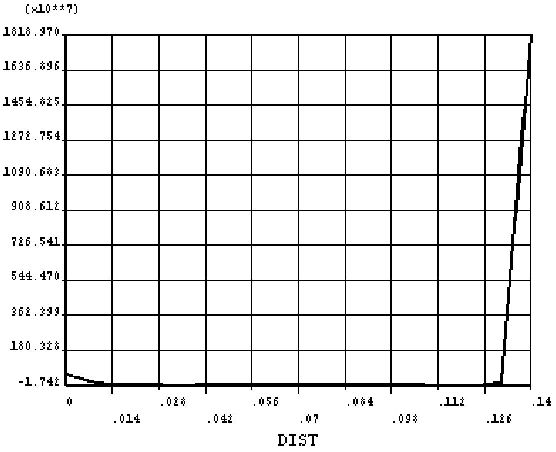

Fig. 5(f). Stress in Z-axis (Pa)

The nodal displacements and stress distribution exhibit similar behavior at different loads. Only the extent of displacement and stress varies against applied load. Fig. 6(a) – Fig. 6(f) show results for 2489.3 N loads.

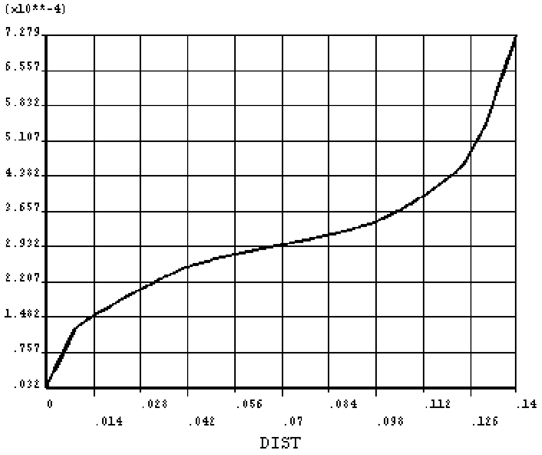

Fig. 6(a). Displacement in X-axis (m)

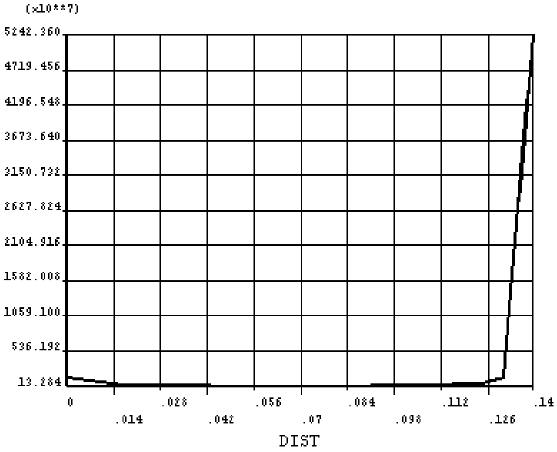

Fig. 6(b). Stress in X-axis (Pa)

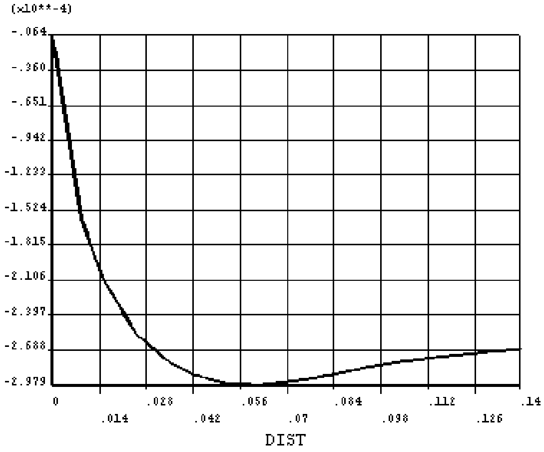

Fig. 6(c). Displacement in Y-axis (m)

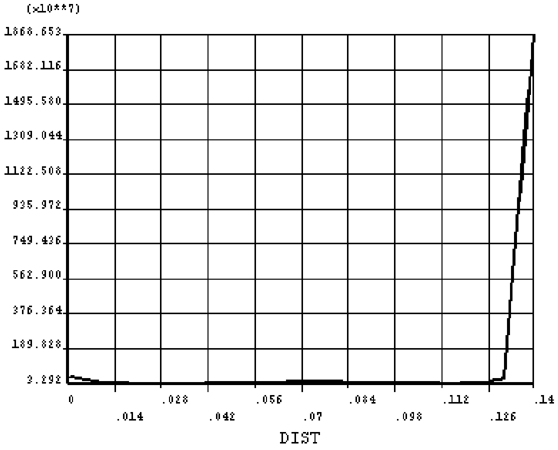

Fig. 6(d). Stress in Y-axis (Pa)

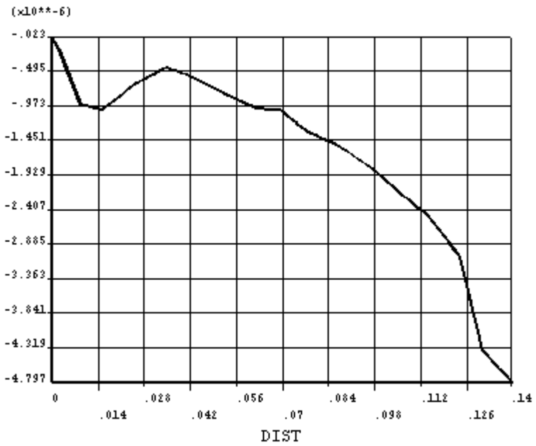

Fig. 6(e). Displacement in Z-axis (m)

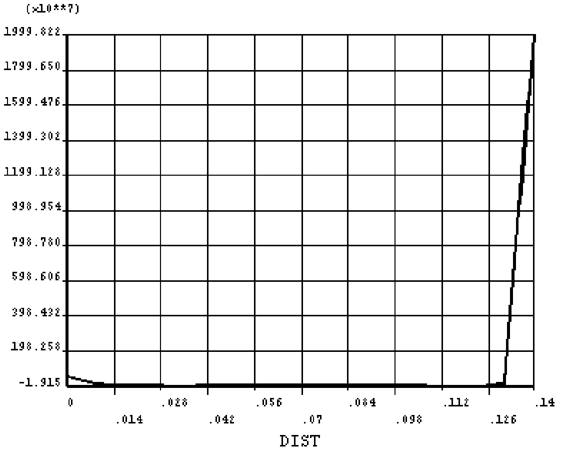

Fig. 6(f). Stress in Z-axis (Pa)

Results of displacement and stress distribution for 2036.7 N loads are shown in Fig. 7(a) – Fig. 7(f).

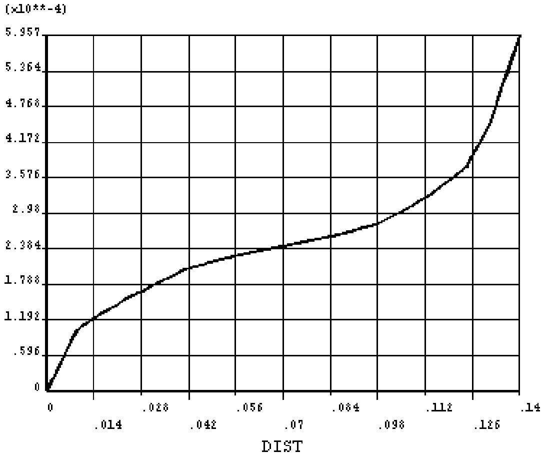

Fig. 7(a). Displacement in X-axis (m)

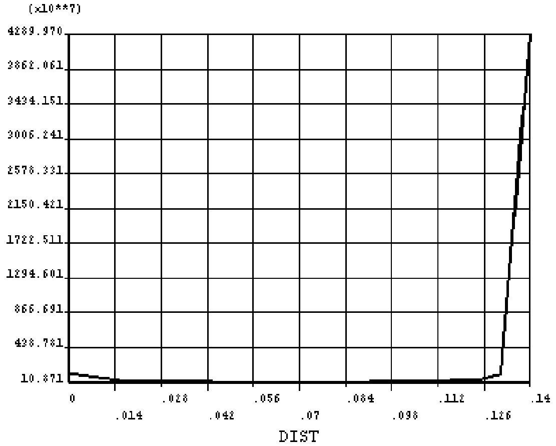

Fig. 7(b). Stress in X-axis (Pa)

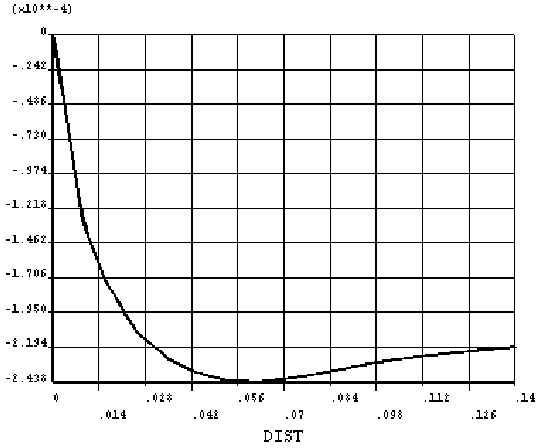

Fig. 7(c). Displacement in Y-axis (m)

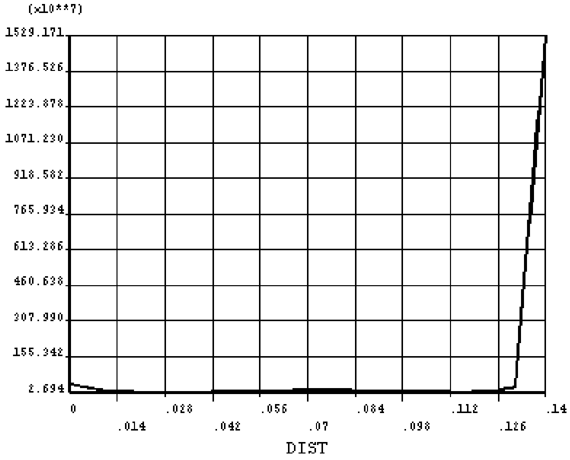

Fig. 7(d). Stress in Y-axis (Pa)

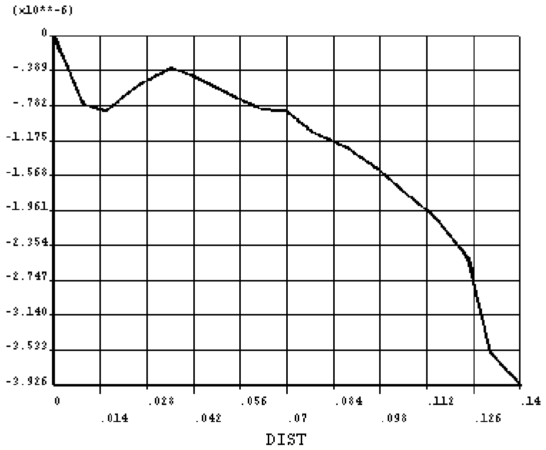

Fig. 7(e). Displacement in Z-axis (m)

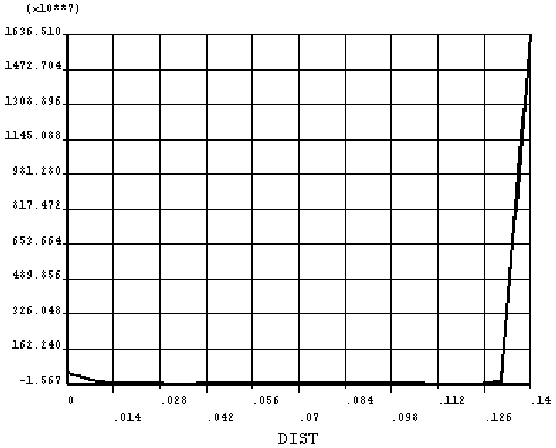

Fig. 7(f). Stress in Z-axis (Pa)

IV. DEDUCTIONS

The graphs show variation in different axis (X, Y and Z) corresponding to the applied load. It can be easily deducted that the portion of sample, which is away from the line of application of load, experience small displacement as compared to the portion directly under the load.

Physically the appearance of wrinkles is observed in the form of longitudinal protrusions of material normal to the direction of applied load. The area where stress concentration is high, wrinkle will be more pronounced. Some examples of wrinkles formation are shown in Fig. 9.

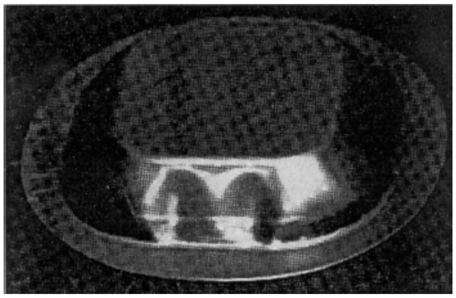

Fig. 9(a). Wrinkles in cup forming [1]

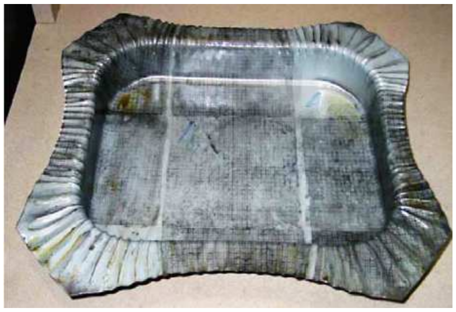

Fig. 9(b). Wrinkles in cup forming [1]

From the graphical results shown in Fig. 2(f), Fig. 3(f) and Fig. 4(f) it can be clearly deducted that stress distribution in Z-axis (normal to the applied load) is varying sharply between minimum and maximum value along the horizontal path line. Moreover the portion of Yoshida Sample on the extremities, experience less stress thus extent of wrinkles is very low, whereas, maximum wrinkle formation occur in the zone in between AA' and BB' (Fig. 1). As the applied load increases the amount of wrinkles also increase.

In case of bidirectional loads the graphical results shown in Figs 5(f), 6(f) and 7(f) indicate smooth variation of stress distribution in Z- axis, thus onset and extent of wrinkles is very low throughout the sample.

V. FINDINGS

From the knowledge of material sciences we know that stress and strain are proportional to each other. The portion of metal which is under maximum stress will be strained maximum and vice versa. The results obtained from the analysis also confirm that nodal displacement along the path is maximized where stress concentration is greater. The higher the load value, higher is the value of wrinkle formation in the sample. Following findings can be inferred from the results:-

a) Wrinkle formation is maximized in the region directly falling under the line of application of load, as compared to the extremities where load is not applied.
b) Only 5% maximum increase in nodal displacement is observed against 10% increase in load in the elastic range of material.
c) Maximum increase in nodal displacement is around 15% against 10% increase in the load value above yield strength of material.
d) Variation in stress distribution along X-axis reveal –ve value i.e., compression, and along Y-axis the sample experience tensile stress.
e) As a result of both tensile and compressive stresses in the sample, the stress component in Z-axis varies between alternating +ve and –ve values. This consecutive variation between compressive and tensile stress, normal to the sample surface, result in wrinkle formation.
f) In case of bidirectional load, wrinkle formation is almost eliminated. This shows that apart from load value, the arrangement of load application play a very important role in wrinkle formation.

VI. CONCLUSION

The use of FE analysis software tools has magnanimously enhanced ease in research work by saving on the time as well as expensive and extensive time consuming experimental tests. Once the analytical results compared to the preliminary experimental results conform, then sound basis is established for computer simulations and implementation in the final design of products without going into repeated experimentation. The results of current analysis will provide a basis for the simulation and analysis of wrinkle formation in different sheet metals under varying load applications.

REFERENCES

[1] Xi Wang, Jian Cao, prediction of side-wall wrinkling in sheet metal forming processes, International Journal of Mechanical Sciences 42 (2000)

[2] J Hematian and P M Wild Initial imperfections and the initiation of wrinkling in finite element modeling of deep drawing, Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering(2000)

[3] Hakim S. Sultan Aljibori, Finite Element Analysis of Sheet Metal Forming Process, European Journal of Scientific Research ISSN 1450-216X Vol.33 No.1 (2009)

[4] Ronaldo I. Borja, Finite element simulation of strain localization with large deformation:ELSEVIER, Comput. Methods Appl. Engrg. 191 (2002) 2949-2978

[5] A. Selman et al, Adaptive Numerical Analysis of Wrinkling in Sheet Metal Forming, Netherlands Institute for Metals Research - Rotterdamseweg 137 - 2628 AL Delft - The Netherlands

[6] Xiafeng Su, Frank Abdi et al, wrinkling analysis of a Kapton square membrane under tensile loading, 44th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Material Conference 7-10 April 2003, Norfolk, Virginia.

[7] H.S Cheng, J. Cao et al, Wrinkling behavior of laminated steel sheets, Journal of material processing technology 151 92004) 133-140.

Jawad Ahmed Jadoon is a researcher at HITEC University of Engineering and Management Sciences, Department of Mechanical Engineering. He got his Beachlor’s Degree in Mechanical Engineering from University of Engineering and Technology Peshawar, Pakistan, in 1989. He is currently enrolled as MS Mechanical Engineering student at HITEC, Unisersity, Taxila. His research interests are Finite Element Methods for prediction of manufacturing and design failures of engineering components.

Dr. Irfan Anjum Manarvi is an Associate Professor at HITEC University of Engineering and Management Sciences, Department of Mechanical Engineering, Taxila. He received his Aerospace Engineering Degree from College of Aeronautical Engineering Pakistan Air Force Academy Risalpur. He later received M Phil and Phd from the Department of Design Manufacture and Engineering Management, University of Strathclyde Glasgow United Kingdom.. His research interests are FEM and CFD applications for structural and aerodynamic failures in aircraft engines, CAD/CAM/CAE, small satellite design and manufacture, dimensional tolerance synthesis, aesthetics in engineering, manufacturing processes, sheet metal forming and machining.