Wrinkling Prediction of Aluminum 5456-H116 sheet Metals under Uni-Axial and Bi-Axial Loading through FE Simulations

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***Abstract*— Wrinkling is one of the most undesirable defects in forming processes, especially when dealing with thin sheets. Methods have to be devised to control the extent of damage. This defect if left un-attended can cause irretrievable loss. Remedial measures include proper constraining of the thin sheet as well as appropriate loading techniques.FEM software can be effectively used not only to predict the extent of damage, but damage control measures can also be simulated to suggest appropriate action to be taken at forming stage. This would drastically cut the cost incurred to remove the "Wrinkles" at later stage. Removal of this defect after the forming process may be not only expensive but sometimes impossible, as has been observed in die making. Present research was focused on using Finite element software to predict the possible remedial measures to be adopted. These results could then be used as reference for carrying out non destructive analysis of this problem, leading to savings in inspection cost, lesser repair time and more focused fault isolation.**

***Keywords*—** Finite Element Analysis (FEM), Stress, Displacement, Wrinkles, and Yoshida Test

I. INTRODUCTION

Wrinkling in thin metal sheets in the early drawing and forming processes if not addressed properly can lead to failure by "Buckling". It has been established that one of the most commonly observed failure modes in the conventional drawing processes is due to wrinkling and this defect arises due to lack of hold down forces [6]. This research paper focuses on this phenomenon by constraining ends along X-axis and Y-axis and applying tensile forces on the opposite ends. Experimental work confirmed that these defects are formed due to elastic-recovery deformation after the forming process; this elastic recovery stage has close relationship with the initiation, growth and removal of buckling as proposed by Yoshida in the fitting-behavior diagram [7]. The mechanical properties of thin sheets are different from the bulk materials, the fact which has come to limelight due to better measuring tools now available to engineers. The miniaturization of the forming geometry causes the so called "scaling effect", which leads to a different material behaviour in the micro scale compared to the macro scale [8]. Thus it has become imperative to study material properties and their behavior when small dimensions are encountered during manufacturing processes. In this paper focus is on thin sheet of .2mm thickness. There are likely chances that deformation would become inhomogeneous on application of forces, which can initiate yielding in the material. In deep drawing processes engineers require that yielding should occur in the flanges of work-piece before wrinkling occurs to improve the quality of end product. This is the reason behind operating near the yield point of the material, in this research. Some researchers have assumed that the specimen has not yielded. This appearance is called elastic wrinkling [9].It has also has been confirmed that wrinkling basically occurs due to non-uniform tension. Wrinkling of a rectangular plate subjected to a parabolic tensile traction distribution along its loaded edge has also been examined [10].It has also been ascertained that Bending stiffness plays an important role in the wrinkle shape [1]. This was primarily the reason to select a material with low modulus of rigidity, in this research paper.

Present research was focused on wrinkling prediction of Aluminum Alloy 5456-H116 allo sheet by applying loads equivalent ±10% of the tensile yield strength.Its properties were; Modulus of elasticiy as 72 GPa, Poisson's ratio as 0.31, Yield strength as 230 MPa. A thickness of 0.2mm was used for FEA. It was was modelled in form of a Yoshida specimen and meshed in Ansys Software selecting an isotropic material using "Brick node 87 type element" . The plate was constrained in all degrees of freedom at the base and left end while being subjected to uniform loading on all key points along X-axis as well as Y-axis.

Fig. 1 below shows loaded & Constrained Specimen.

Fig. 2 below shows displacement in case of uni-axial loading.

Fig. 3 below shows displacement in bi-axial loading.

It was observed that there is hardly any change in the contour of displacement line at -10% Yield Stress, at Yield Stress and at +10% Yield Stress in case of bi-axial loading.

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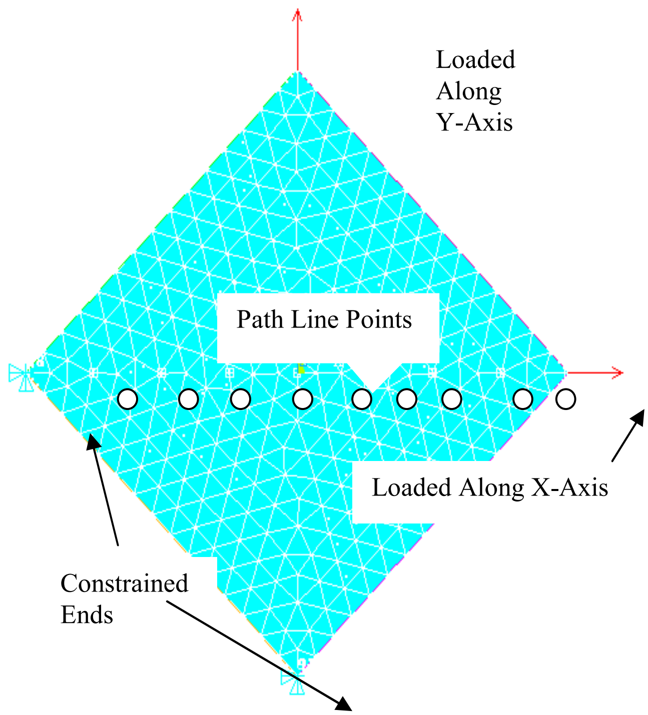


Fig. 1. Loaded & Constrained Specimen

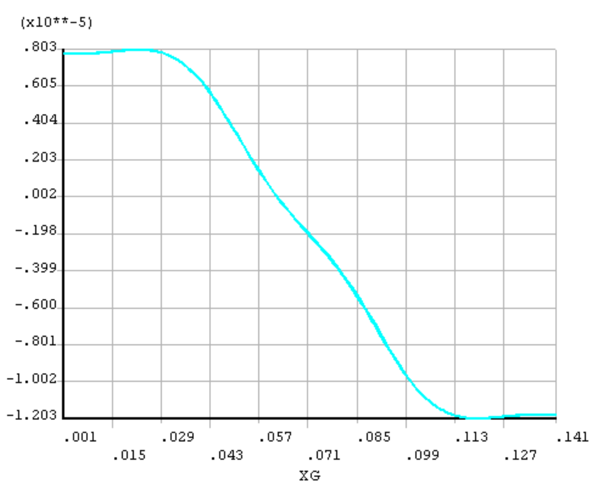


Fig. 2. Displacement of path line points in case of loading applied along Y-axis only

The above results were obtained when magnitude of applied load was such as to cause stresses close to the yielding strength of the material. The displacement near the constrained end is zero, while it becomes maximum near the applied load end. There is very less variation in the displacement at the middle as points being pulled along both axes tend to stick to their positions.

Fig. 4 below shows stresses in case of loading along Y-axis.

It is observed that there is large fluctuation of stresses along the path line points. Particularly note that there is compressive stress at the middle point. Also note that stresses are higher than the yield strength of the material, which is close to 270Mpa.

Fig. 5 below shows stresses while specimen is loaded in both axis.

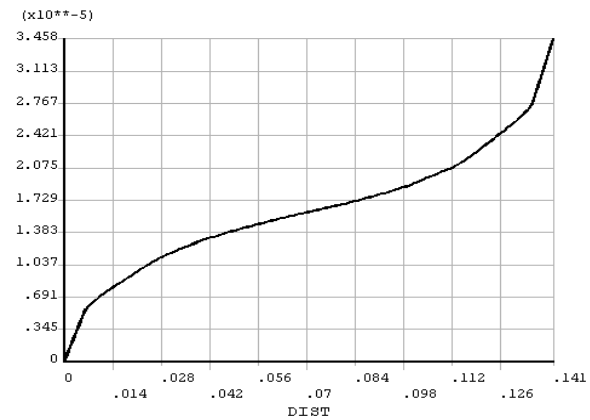


Fig. 3. Displacement of path line points in case of bi-axial loading along Y-axis & X-axis, with opposite constrained ends

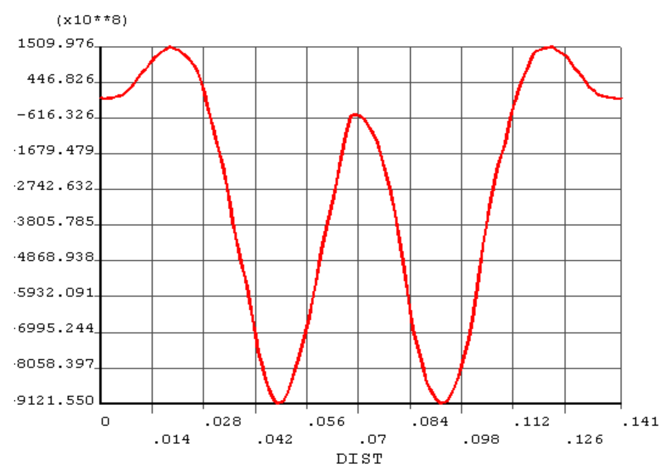


Fig. 4. Stress in case of uni-axial loading along Y-axis

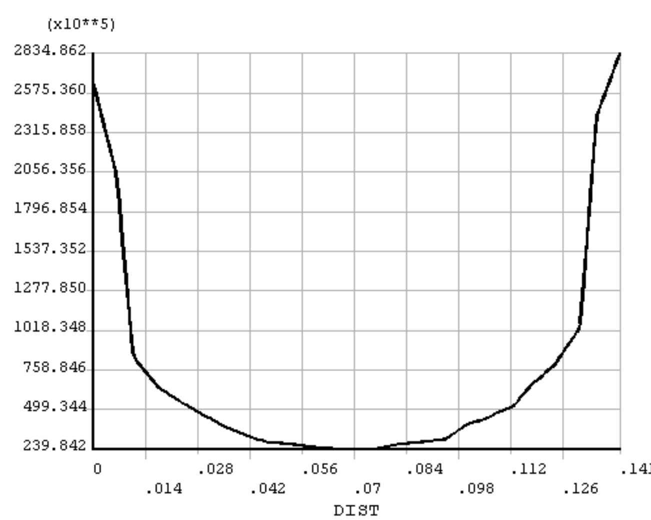


Fig. 5. Stress in case of bi-axial loading along X-axis & Y-axis

In comparison to uni-axial loading the stresses at the middle points on the path line are least while a steep increase in their values is noticed at the ends. The values at the end are close to yield strength of material. The variation in the stress values near the middle do not vary too much. This was expected as we had already observed that variation in displacement values in the middle also were minimal.

III. DISPLACEMENT & STRESSES ALONG Y-AXIS

Fig. 6 below shows displacement while specimen is loaded along Y-axis.

Displacement at the farthest end shows maximum displacement. This shows that there is miss-alignment of tensile force which is mainly responsible for buckling and ultimately occurrence of wrinkling.

Fig. 7 below shows displacements if specimen is loaded along X & Y axis while constraining the other two ends.

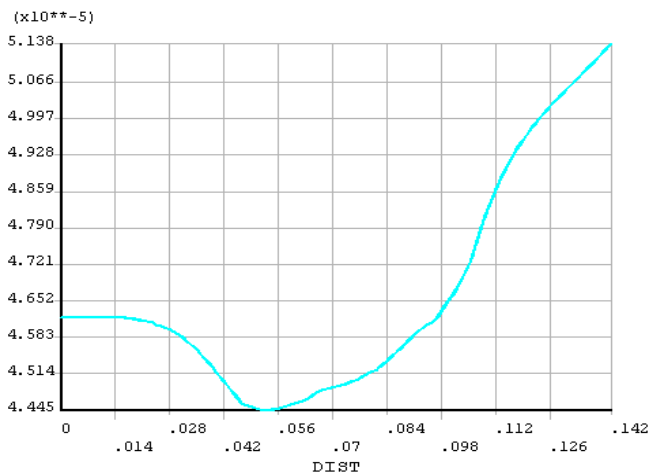


Fig. 6. Displacement of path line points in case of uni-axial loading along Y-axis, while constraining the other end

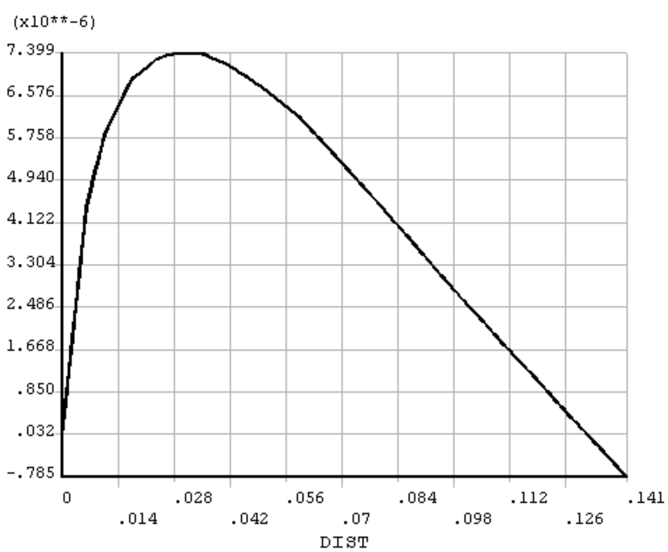


Fig. 7. Displacement of path line points in Bi-axial loading

It is observed that displacement values have been reduced significantly. This seems to be apparently as a result of constrained ends along X-axis and Y-axis. So the maneuverability of the path line points has been restricted. Moreover there is steep decrease in the displacement value at the ends of path line, thereby showing that there is almost negligible displacement at the constrained end as well as at the point of application of tensile force along X-axis. This point can further be elaborated by observing stress values in the Y-direction.

Fig 8 below shows stresses in case loading applied along Y-axis, while constraining the other end.

Stress at the middle points is maximum except a small dip in the value. Moreover values at the ends of path line are negative thereby showing that compressive stresses have developed. Maximum stress at the middle is in line with the line of action of load.

Fig. 9 below shows stresses if specimen is loaded along X-axis & Y-axis.

The behavior of stress pattern has completely changed. A number of points in the middle of path line show least stress values. Moreover note that none of the stress value is near the yield strength of the material. It is inferred that bi-axial loading is going to prevent the permanent wrinkling phenomena.

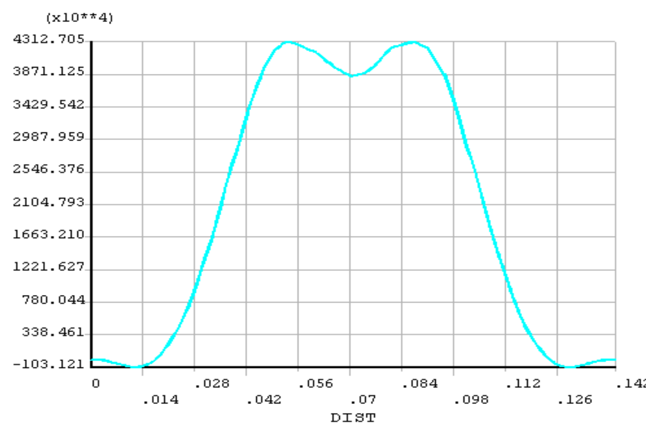


Fig. 8. Stress at the path line points in Uni-axial loading

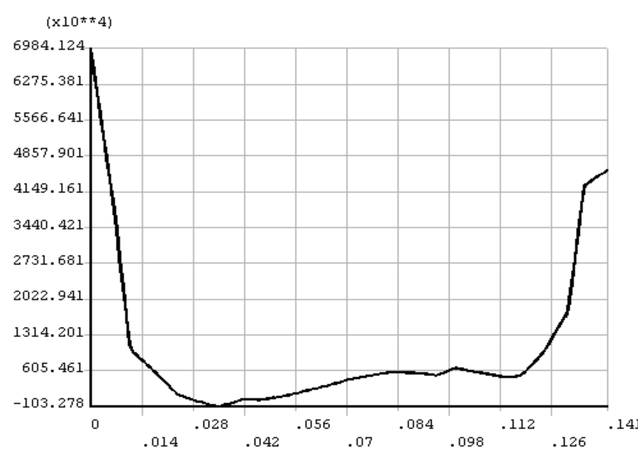


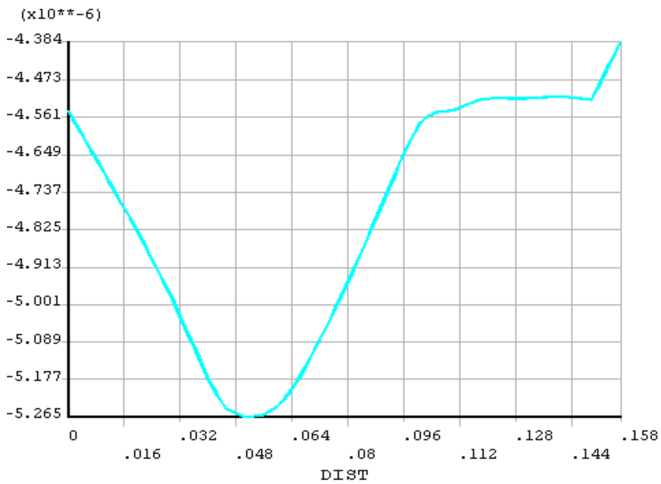
Fig. 9. Stress at the path line points in Bi-axial loading

IV. DISPLACEMENT & STRESSES IN Z-AXIS

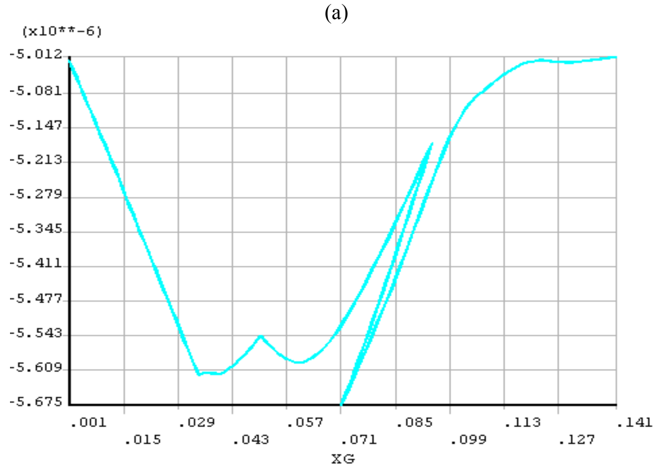
Z-axis displacement and stresses can also be termed as out of plane for the reason that in this paper all the constraints and loading is in X-Y plane. There would be only lateral effects which would be of paramount importance. This is the reason behind giving significance to Poisson's ratio whenever wrinkling phenomena is studied. It is expected that pronounced wrinkling effects would be evident in the plane which is perpendicular to X-Y plane that is out of plane. These facts are highlighted in the figures presented in this section.

Fig. 10 (a), (b) & (c) show the displacements of path line points for three different types of loading.

The results for displacements, over the path line almost show same pattern. There is increase in magnitude of displacement near the middle points of path line. More important is relative displacement values of different points. This relative displacement is 1μm, the highest in case of loading corresponding to +10% yield Strength.



(a)



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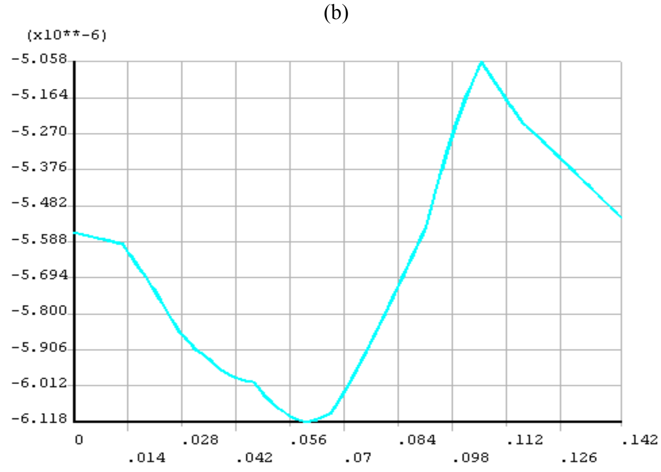
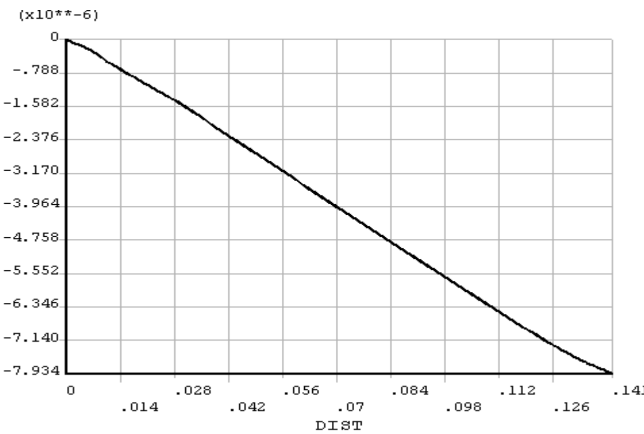
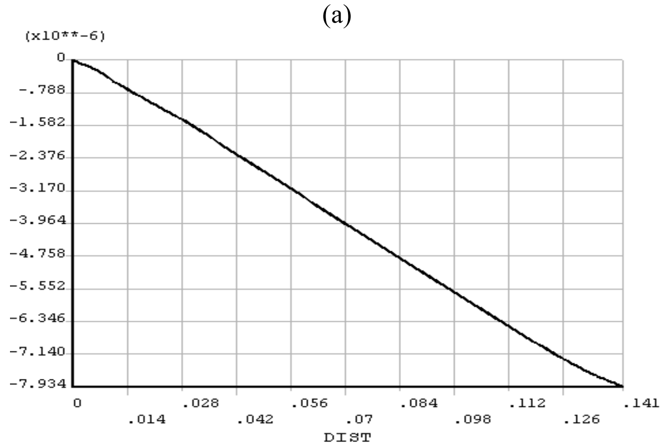


(c)

Fig.10 Displacements along path line in Uni-Axial Loads corresponding to -10% Yield Strength, Yield Strength and +10% Yield Strength respectively



(a)



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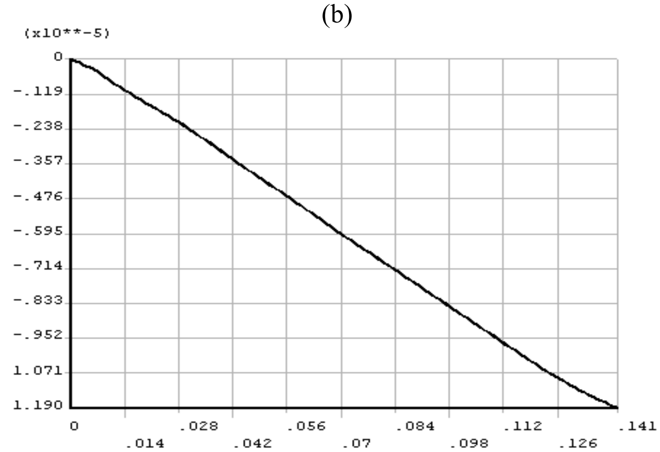


(c)

Fig. 11. Displacements along path line in Bi-axial loads corresponding to -10% Yield Strength, Yield Strength and +10% Yield Strength respectively

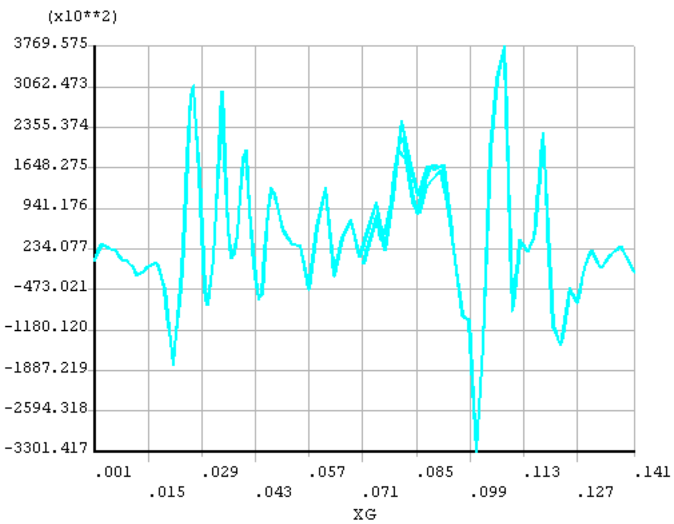
In case of initial load the maximum displacement out of plane comes out to be .704µm. In case of loading corresponding nearly to yield strength of material, the maximum displacement remains constant. Ultimately it shoots to maximum value mentioned above in case of maximum loading.

Let us observe the behavior in case of bi-axial loading.

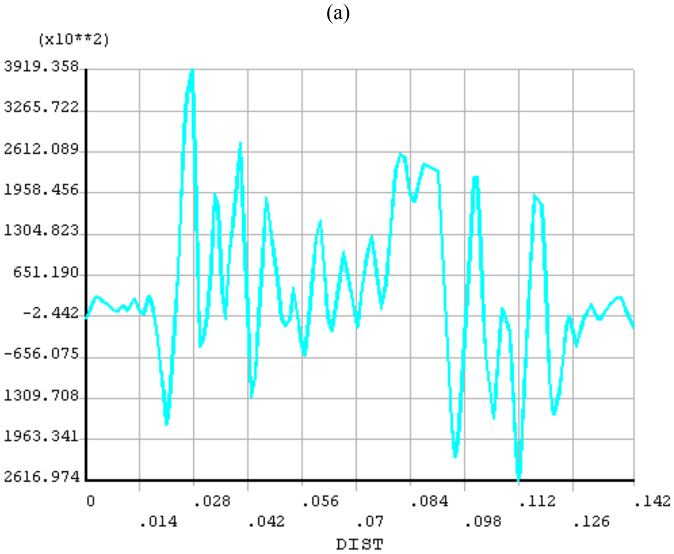
Fig. 11 (a), (b) & (c) show the displacements of path line points for three different types of loading in bi-axial loading.

Displacement values in Fig. 11 show same pattern of increase from left end of path line to right end. The relative increase is maximum in case of maximum loading. Note that relative displacement is 1µm for maximum loading. This relative displacement is responsible for out of plane wrinkling.

Fig. 12 (a) & (b) show the stresses along path line points for three different types of loading.



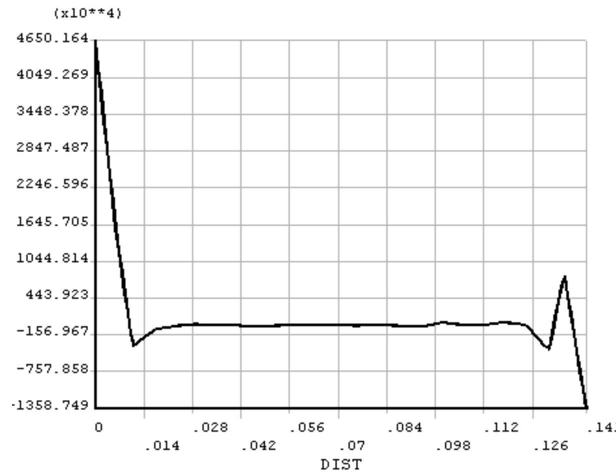
(a)



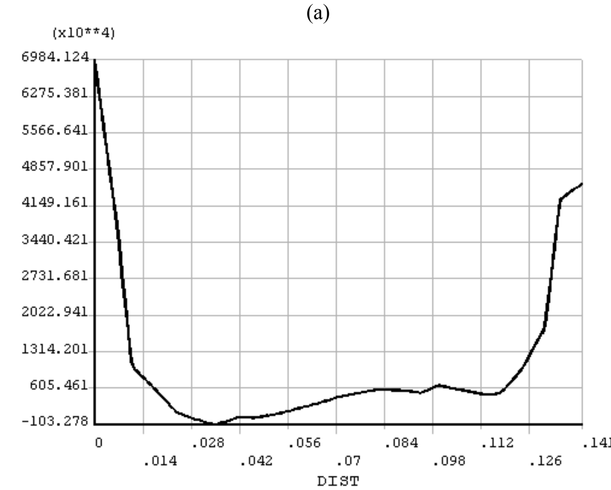
(b)

Fig. 12. Stresses along path line in Uni-Axial Loads corresponding to Yield Strength and +10% Yield Strength respectively

Stress pattern supports the earlier displacement pattern in case of uni-axial loading. There was minimum relative displacement between end points of path line and in the same way there is almost same stress value at the end points. Note however that there is significant variation in stress value from positive to negative values, thereby confirming that bending



(a)



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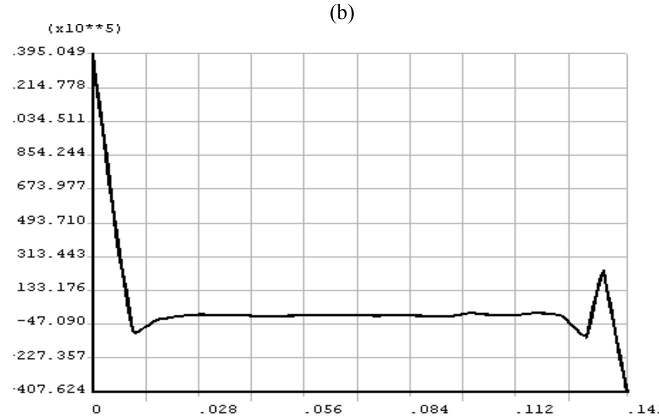

(c)

Fig. 13 shows stresses along path line in Bi-Axial Loads corresponding to -10% Yield Strength, Yield Strength and +10% Yield Strength respectively phenomena is occurring, which would ultimately result in wrinkling. Let us compare it with stresses resulting from bi-axial loading.

Fig. 13 (a), (b) & (c) show the stresses of path line points for three different types of loading.

It appears that bi-axial loading has to large extent arrested the tendency of fluctuation in the stress values found in case of uni-axial loading. But at the same time it is puzzling to note that it has been not able to cease the relative displacement of the points along the path line.

V. FINDINGS

Present research was based on using Ansys for structural problems. Extensive simulations resulted into following major findings:

A. Wrinkling has not subsided in case of out of plane displacements by resorting to bi-axial loading while constraining the opposite ends.
B. In case of displacement along X-axis the maximum relative displacement in case of uni-axial loading comes out to be 20.06 µm as compared to 34.5 µm in case of bi-axial loading. Thus bi-axial loading has not constrained the wrinkling along X-axis.
C. In case of displacement along Y-axis, in uni-axial loading maximum relative displacement comes out to be 6.93µm while for bi-axial loading it comes out to be 7.367µm. Thus there is hardly any improvement to arrest the tendency of wrinkling by applying bi-axial loading.
D. The stress distribution is only supporting the corresponding displacements obtained for a particular type of loading and has thus not contributed much to the study of wrinkling.
E. The comparison between two types of loading has proved that the way the bi-axial loading was applied is not going to help in reduction of wrinkling.

VI. CONCLUSIONS

Present investigation was focused on evaluating the possibilities of using FEM for prediction of wrinkling and suggesting ways to reduce the impact of this defect by shifting from uni-axial loading to bi-axial loading. It confirmed that present technique adopted was not successful and other methods need to be evolved. Nevertheless the simulations provided an insight to the wrinkling problem and sparked the motivation to further probe this problem.

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