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Design and Analysis of Technique of cold bending of Glass Plate

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ABSTRACT

The paper represents the determination and behavior of glass plate under cold bending technique at ambient condition. Analysis of this technique revels the bending of a glass plate shows that it won't affect the properties of glass plate after bending. This paper consist of design the technique in which discover appropriate locations on glass plate by applying forces at different points to obtain bending of glass plate up to certain limit for parabolic shape without breakage.

Parabolic shaped glass bending plate useful for various applications as in solar collectors which is used for heating water. Though Aluminum plate uses in solar collector, it has good efficiency, good reflectivity and better yielding properties than other materials. But its parabolic shape is not perfect. Because of imperfect shape, there is power loss due to no concentration of radiation at focal distance and it deviated.

Now a day's bending of glass plate is done by hot bending but it has a limitation to get parabolic shape and also affect on properties of glass plate.

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I. INTRODUCTION

The solar collector used for minute power generation. The parabolic solar collector has the efficient curve to concentrate maximum radiations. This uses the aluminium plates which bent in parabolic shape. As the aluminium has superior reflectivity and better yielding properties than other materials, it widely used. But still aluminium has not cent percent reflectivity. So this drawback can be removed by means of material close or equal to very high reflectivity which is nothing but the mirror. The mirror has very high reflectivity, which can concentrate total radiations fall on it at particular location. But mirror has poor yielding properties which causes the brittle failure. But still it can sustain yielding up to a few extent.A parabolic trough solar collector uses a mirror in the shape of a parabolic cylinder to reflect and concentrate sun radiations towards a receiver pipe located at the focus line of the parabolic cylinder. The receiver absorbs the incident radiations and transforms them into thermal energy, the latter being transported and collected by a fluid medium circulating within the receiver tube. This method of concentrated solar collection has the advantage of high efficiency and small cost, and can be used either for thermal energy collection, for generating electricity or both; therefore it is an important way to exploit solar energy directly.

If the parabolic shape is not perfect then the radiations cannot be capable to concentrate at its focal distance and the radiations deviates from it. This causes loss of radiations and indirectly the loss of power.

The traditional manufacturing process to form the parabolic cylinder reflective surface consists of forming a curved plate material under high temperature. The flat glass is heated beyond the weakening point and gradually curved in a heavy forming mould. After cooling down, the resulting glass element can maintain its fresh shape without the need of extra boundary conditions. Disadvantages of this technique are costs of moulding, high energy consumption and risk of optical distortions. For this reason, valuable different techniques have been developed, which do not need treatments at elevated temperatures and which are therefore called "cold" bending processes .These processes imply the bending of toughened float glass laminates and their fixation to a curved frame. In order to verify the load-carrying capacity, glass panels was subjected to experimental static loading tests. This paper is based on the study of behaviour of glass under bending at ambient conditions and method of bending it, which forms perfect parabolic profile and can be used as solar collector to work it at higher efficiency

II. Introduction of the Plate

Plates are straight, flat and non-curved surface structures whose thickness is slight compared to their other dimensions. Generally plates are subjected to load conditions that cause deflections transverse to the plate. Geometrically they are bound either by straight or curved lines. Plates have free, simply supported or fixed boundary conditions. The static or dynamic loads carried by plates are predominantly perpendicular to the plate surface. The load carrying action of plates resembles that of beams or cables to a certain extent. Hence plates can be approximated by a grid work of beams or by a network of cables, depending on the flexural rigidity of the structures. Plates are of wide use in engineering industry. Nowadays, plates are generally used in architectural structures, bridges, hydraulic structures, pavements, containers, airplanes, missiles, ships, instruments and machine parts. Plates are usually subdivided based on their structural action as

1. Stiff Plates, which are thin plates with flexural rigidity and carry the loads two dimensionally. In engineering practice, a plate is understood as a stiff plate unless specified
2. Membranes, which are thin plates without flexural rigidity and carry the lateral loads by axial shear forces. This load carrying action is approximated by a network of stressed cables since their moment resistance is of a negligible order of magnitude.
3. Flexible Plates, which represent a combination of stiff plates and membranes. They carry external loads by the combined action of internal moments and transverse shear forces.
4. Thick Plates, whose internal stress condition resembles that of three dimensional structures.

Cold Bent Single Curved Glass

The concept of "cold" bending of flat panels is a well know concept in industry in general. Materialization can range from plastics to wood and metals as shown in fig.2.

Figure 1. Cold bent Plexiglas in Bio Solar Haus in Germany [9]

In cold bent materialization, glass does not seem to be the most understandable choice. The common perception of glass is still a brittle material with hardly any strength capabilities. The perception of glass as a brittle material is accurate. The perception of glass having little strength is commonly based on a misunderstanding. Over the last 20 years, an increasing amount of project and experiments were conducted with glass as main carrying component. To support this development, codes and standards have been developed on maximum allowable tensile bending strength of glass.

Supported by Finite Element Method-Software and these well defined codes and standards at hand, investigation of material's boundaries is more accessible. A study of cold bending of glass is one of the possibilities to support freeform architecture with a transparent materialization. [9]

III. Plate Equation

There were many plate theories formulated. The Euler–Bernoulli beam theory as the engineer's beam theory is the linear theory which provides a means of calculating the load-carrying and deflection characteristics of beams. Out of numerous plate theories that have been developed since the late 19th century, two are widely accepted and used in engineering. They are

1. The of plates Classical plate theory of Kirchhoff–Love
2. First-order shear plate theory of Mindlin–Reissner

According to Kirchhoff, the assumptions were considering a mid-surface plane which helps in representing a three dimensional plate in two dimensional form. The basic assumptions are:

1. The normal lines remain straight after deformation.
2. The normal remain the same length
3. The normal remain at right angles to the mid surface after deformation.

The plate equation is derived by assuming plate is subjected to lateral forces, the following three equilibrium equations are considered

$$\sum Mx = 0$$
$$\sum My = 0$$
$$\sum Pz = 0$$

Where, Mx and My are bending moments and Pz is the external load. The external load Pz is carried by transverse shear forces Qx , Qy and bending moments Mx, My. The plates generally have significant variation from the beams and it is due to the presence of twisting moment Mxy.

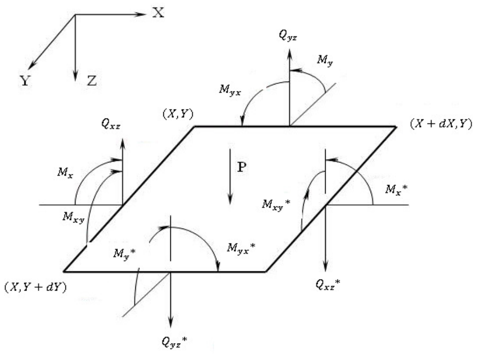

Figure 2: Differential Plate with Stress Resultants

$$Mx= -D\left(\frac{\delta}{\delta} + \frac{\delta}{\delta}\right)$$

$$My= -D\left(\nu\frac{\delta}{\delta} + \frac{\delta}{\delta}\right)$$

$$Mxy=Myx = -D\,(1-)(\nu\,\frac{\delta^2}{\delta x\delta})$$

If the resultant moment about an edge parallel to the X and Y axes is set to zero then the resulting equation after neglecting the higher order terms gives

$$\frac{\delta}{} + \frac{\delta M}{\delta} + Qxz =$$

$$\frac{\delta}{\delta} + \frac{\delta}{\delta} + Qyz =$$

$$\frac{\delta^2}{\delta} + \frac{\delta^2 M}{\delta x\delta} + \frac{\delta^2}{\delta} = -Pz(x,$$

$$\frac{\delta}{\delta} + 2\frac{\delta^4}{\delta x^2\delta} + \frac{\delta^4}{\delta} =$$

$$\nabla^4 W =$$

Where,

$$\nabla^4 = \frac{}{\delta} + 2\frac{\delta^4}{\delta x^2\delta} + \frac{}{\delta}$$

And,

$$D= \frac{E\,h^3}{12\,(1-}$$

Where,
D- Flexural rigidity of the plate
E- Young's modulus of the plate
h- Height of the plate
ν- Poisson's ratio

Boundary conditions

Generally, there are different types of boundaries considered for a plate in terms of lateral deflection of the middle surface of the plate and they are:

1. Clamped edge Conditions
2. Simply Supported edge Conditions
3. Mixed edge Conditions
4. Free edge Condition

Deflections of plate as a parabola

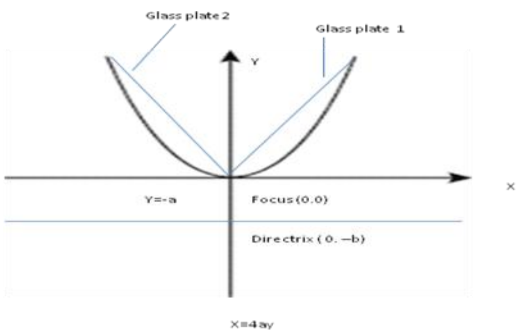

Figure 3: The Parabola of focus on y axis

In this project we are considering equation as per fig 2. Here two parabolic mirrored plate forms one complete parabola of solar collector. In this project we are considering only mirrored plate 1 as shown in fig 2 as other side is symmetry. After bending the mirrored plate, combining of two it will form the one parabola. So the main objective is to bend the mirrored plate for half of the original parabolic shape.

IV. DETAILS OF ANALYSIS

a In analysis the main area initially we have to concentrate a support condition. The mirrored plate boundary conditions are used simply supported and it means its edges are free to move horizontally

There are basically two types of analysis linear analysis and nonlinear analysis. When structural response i.e. deformation, stress and strain are linearly proportional to the magnitude of load then the analysis of such a structure is known as linear analysis. When the load to response relationship is not linearly proportional, then the analysis falls under nonlinear analysis. E.g. when a compact structure made of stiff metal is subjected to the load with relatively lower in magnitude as compared to load strength of the material, the deformation in the structure will be linearly proportional to the load and structure is known to have subjected to the linear static deformation but if it is not like that then that structure is known to have subjected to the nonlinear static deformation.

The stiffness matrix relating to the load and response is assumed to be constant for static analysis, however all the real world structures behave nonlinear. The stiffness matrix consist of geometric parameter like length, cross sectional area and moment of inertia of the section etc. and material properties like elastic modulus etc. the static analysis assumes that these parameters do not change when structure is loaded, on the other hand nonlinear static analysis takes in to account the change in these parameters as load is applied to the structure. These changes are accommodated into the analysis by rebuilding the stiffness matrix using deformed structure configuration and updated property after each incremental load application.

Types of nonlinearity:

There are three basic three types of nonlinear analysis:

1. Geometric nonlinear
2. Material nonlinearity.
3 Boundary nonlinearities

Geometric Nonlinearities:

A fishing rod is the common example of a familiar structure that is bending so dramatically that this behaviour is observable, and it fits into the definition of geometric nonlinearity, that is a situation where the displacement does not a straight-line response to the applied loads. It also has very large displacements and rotations.

Stiffness changes due to geometric deformations are categorized as geometric nonlinearities.

Following are the different kinds of geometric nonlinearities.

a. Large strain:

If an elements shape changes i.e. area, thickness etc., its individual element stiffness will also change.

b. Large rotation:

If an elements orientation changes i.e. rotation, the transformation of its local stiffness will change.

c. Stress stiffening:

This is associated with tension bending coupling. More the tension in the membrane, more it’s bending rigidity or stiffness. If an elements strain produce a considerable in plane stress state i.e. membrane stresses, the out of plane stiffness can be considerably affected.

Material nonlinearity

All engineering materials are inherently nonlinear as it is not feasible to characterize a nonlinear material for the entire range of environment conditions such as loading, temperature and rate of deformation. We can simplify the material behaviour to account for only certain effects which are important for the analysis. The linear elastic material assumption is the simplest of all. The material is nonlinear elastic if the deformation is recoverable and plastic if it is irrecoverable material.

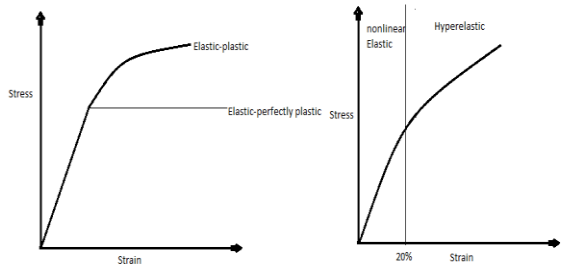

Figure 3: Comparison of material linearity and nonlinearity

Boundary nonlinearities

Boundary nonlinearity arises when boundary conditions in a FE model changes during the course of analysis. The boundary conditions could be added or removed from the model due to boundary nonlinearity as the analysis progresses. This kind of nonlinearity involves contact sets in the model which could get engaged or disengaged as a response to applied loads. The load transfer mechanism via contact pair is complicated phenomenon. Researchers have developed numerous theories to describe load transfer via contact sets.

As the bending of the mirrored plate under consideration has large deformation in bending, the analysis of the plate falls under stress stiffening nonlinear geometrical analysis.

For the maximum design reliability, particularly when applying a material which is not commonly utilized by engineers, one of strategies is to use a detailed design finite element engineering simulation software. This creates an alternative to physical test as set up of a numerical model has to be prepared as close to the real physical model as possible. The finite element method (FEM) software ANSYS/HYPERMESH was utilized for simulation as it has single potential for design of various complexity structural components. In ANSYS/HYPERMESH code the model is divided into finite elements for analyzing thin to moderately thick shell structures (Figure 3). The main goal was verify the numerical results against the experimental test data. A single glass sheet has been tested initially and then manufactured glass laminate decks composed from two to three glass sheets. [10]

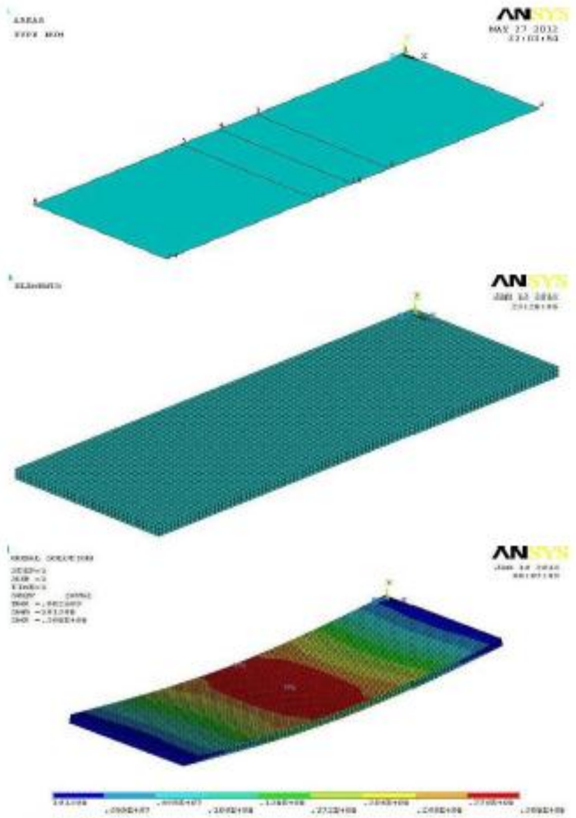

Figure 3 a) model geometry; b) FE meshed structure; c) deformed state [10]

V. CONCLUSION

Using single curved cold bent glass has great potential in solar system, architecture use. Developing curved surfaces to single curved geometries, proves to be a less expensive option. Due to large surfaces used in architecture and solar panel, visual distortion is minimized. Cold bending is the one of the best method to bend the glass. Further research is needed in material bend in various angles.

Structurally, determining the limitations of cold bending of glass is a work in progress. The scope of the study for the near future will be a advance investigating of the behaviour of layer panels of glass. The aim of this future research is to develop practical and time efficient calculation methods for cold bent of laminated and insulated glass.

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