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Design and Simulation of an Egg Crate

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Abstract-In the present research a simulation study using Inventor Professional Software, was carried out to redesign an egg crate to avoid breakage of eggs and cause less stress to a worker lifting them. For the design of egg crates three different performance parameters namely Von-Mises stress criteria, factor of safety and egg crate deflection were used. Recommended weight limit (RWL) and Lifting index (LI) were also calculated using revised NIOSH lifting equation. The two materials selected were High Density Polyethylene (HDPE) and Polypropylene. Three types of egg crates namely conventional egg crate, modified egg crates with and without lifting handles were chosen. Overall six types of design simulations were studied under the selected performance parameters. On the basis of the study it was found that the crates with handle were better over their counterpart. The performances of two egg crates made up of the materials taken in the present work was almost same.

Key words: Egg crate, NIOSH lifting equation, RWL, LI.

1. Introduction

Suitable measures are necessary for the delivery of eggs to retail markets due to their fragile nature. They need to be stored, handled and transported with extreme care, asaround 3-8% eggs are lost during the process of packaging, collection and transportation to the users. A significant part of egg breakage may also be attributed to the design and quality of egg crates being used for the said purpose. Moreover as loading and unloading of egg crates is carried out manually, various other risk factors may be associated with lifting and moving of egg crates.

For many centuries provision of handles on the object being lifted was being used to enhance safety, efficiency and performance of the workers. Marras et al. (1999) showed that inclusion of handles on boxes might lead to an effect similar to reducing the box weight. Also Ciriello et al. (1993) found that there was a decrease of 16% inmaximum acceptable work load (MAWL)when the lifting was done using handles. Rigby (1973) demonstrated that containers when lifted using handles were less susceptible to being dropped.Research findings also indicated that use of handles was safer and less stressful than working with the loads without handles (Drury, 1980; Garg and Saxena, 1980). They found that there were significantly lower strain effects on physiological and psychophysical strain factors on workers. Jung (2010) in another study further showed that position of handles was also an important factor in the process of liftingEgg crates because of their dimensions and nature, did not have handles and were awkward to lift and carry. There were multiple problems associated with the design of egg crates that lead to loss due to breakage of eggs. During loading/unloading and carrying of eggs, instability of load might lead to further breakage of eggs. Load due to top cratesresulted in lateral and longitudinal deflection of lower crates which might further causebreakage due to compression of adjacent lines of eggs. Two types of egg crates namely pulp egg crates and plastic egg crates are frequently used in Indian market. Theseegg crates are kept one over the other to be stored in the warehouse or whenloaded in a vehicle to transport, in the form of stacks so that the space available may be utilised in a proper and efficient manner. Due to low strength of pulp egg crates they can't be stacked much higher. For a typical pulp egg crate the maximum number of crates that can be stacked range from 20 to 25 while for plastic egg crates the number of crates may vary from 35 to 50.The workers involved in the trade were of the view that there was a need to design an egg crate so that the breakage of eggs may be avoided. Moreover they should be easy to work with as improper handling may increase the loss manifold. The objectives of the present study were (i) to design a crate with a view to minimise the breakage of eggs during transportation and (ii) determine the recommended weight limit (RWL) and LI using modified NIOSH lifting equation.

2. METHOD

A finite element and modeling simulation software (Inventor Professional 2013) from Autodesk Inc. (America) was used for the design of egg crates. A survey was carried out to know the intricacies involved in the trade of lifting and transporting of egg crates. Based on the survey, it was found that a worker usually lifted a stack of 10 egg crates at a time. The crates should have sufficient strength so that the lowermost crate may be able to sustain the load exerted by other crates placed over it. Accordingly, the amount of load which was in the range of 150-170 N to be sustained by the bottom crate was taken as a parameter for the design of crates. In order to facilitate proper lifting and transportation, lifting handles which could be attached to the egg crate were also designed. A uniformly distributed load on the surface of the conventional crate was applied to simulate the deflection of egg crate under the load due to other egg crates stacked above it.The egg crates were testedusing various loadsto generate deflection. Von mises stress, deflection of crate and factor of safety were the three performance parameters selected for the design of egg crates. Since the stresses in a solid body occur in all the three directions, the minimum and maximum stresses occurring at a point were taken as a design parameter. The values ofminimum and maximum stresses, known as first principal stress and third principal stress respectively, was obtained using Von Mises stress criteria.

Figure1: Worker lifting and putting egg crates

Factor of Safety, a ratio of yield strength of material to the stress occurring at a point in the body was another measure selected as a performance parameter. Higher value of factor of safety signified the lower chances of failure of material. Deflection of the crate under load was another important criteria used in the design of egg crates. Various regions where the deflection was occurring were identified by applying the load on the egg crates presently in use. These regions were made extra strong in the redesigned crates to make them able to sustain load and to eliminate deflection. For the design and simulation of the new egg crates, two different materials namely High density polyethylene (HDPE) and Polypropylene were selected. Three different crate models i.e. conventional crate, redesigned crate and redesigned crate with handles were designed and tested using the said software. The FE model was constructed based on existing dimensions of egg crate. The displacements and rotations of the egg crate were fixed on the side faces. A uniformly distributed load of 170 N was applied on the surface of the egg crate. An unstructured mesh having 25520 numbers of elements and 56887 numbers of node was formed for FEA. The convergence factor was taken as 50%.

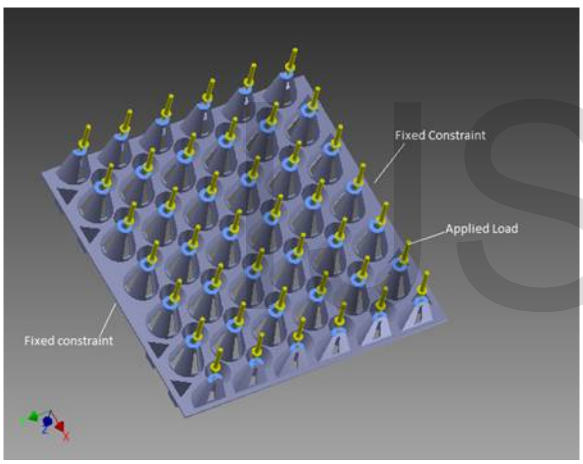

Figure 2. Conventional crate model

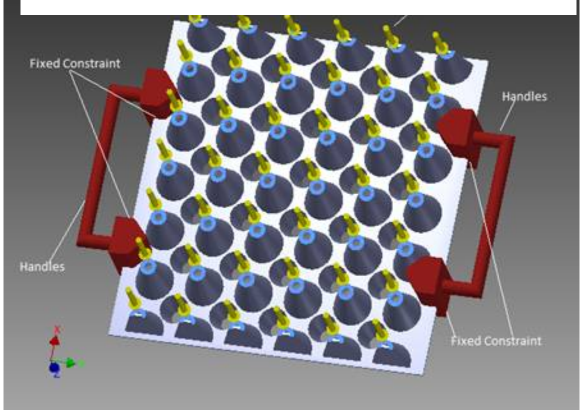

Figure 3. Modified crate with handle

In the present research simulationfor six different egg crate models was carried out. The first and second models were simulated for conventional egg crate with HDPE and polypropylene while the third and fourth models weresimulated for redesigned crates. For the remaining two models, simulation of modified egg crate with handles was performed. For everymodel, a uniformly distributed load of 170N was applied. For simulating the egg crates without handles, fixed constraints were placed on the end contours of the egg crate while for the egg crates with handles, fixed constraints were placed on the handle.

3. Results

The results of the stress analysis obtained using Inventor Professional simulation software on conventional, modified and modified crate with handles have been presented in Table 1.

Table 1. Results of stress analysis

Type of Crate	Material	Von Mises Stress(MPa)		Factor of Safety		Deflection (mm)		
		Max.	Min.	Max.	Min.	X	Y	Z
Conventional	HD Polyethylene	51.8302	0.0174733	15	0.3988	3.908	8.606	24.892
	Polypropylene	51.82	0.0107	15	0.584	2.6559	5.8505	16.92
Redesigned Crate	HD Polyethylene	45.772	0.0365	15	0.5846	2.77	5.95	16.78
	Polypropylene	50.726	0.0305	15	0.597	2.13	4.71	13.31
With Handles	HD Polyethylene	160.766	0.00	15	0.128	0.812	2.141	6.096
	Polypropylene	68.1501	0.00	15	0.445	0.337	1.171	3.264

Revised NIOSH lifting equation was applied to calculate the RWL and LI for the worker performing the lifting tasks. The three positions of lifting shown in Figure 1were used to determine the said parameters, the results of which have been presented in Table2.The Table 2 also showed the values of various multipliers used to calculate RWL and LI using revised NIOSH lifting equation.

Table 2. Results of revised NIOSH lifting equation

		HM	VM	DM	AM	FM	CM	RWL	LI
Without Handles	Case 1	0.71	0.925	0.865	1	0.92	0.9	10.8	1.57
	Case 2	0.71	0.925	0.91	1	0.92	0.9	11.38	1.49
	Case 3	0.71	0.925	1	1	0.92	0.9	12.5	1.36
With Handles	Case 1	0.71	0.925	0.865	1	0.92	1	12	1.42
	Case 2	0.71	0.925	0.91	1	0.92	1	12.64	1.34
	Case 3	0.71	0.925	1	1	0.92	1	13.9	1.22

4. Discussion

Von mises stress provided the criteria for failure of a model tasted under externally applied load. The yield modulus for HDPE was 0.911 GPa while for Polypropylene it was 1.34 GPa. The maximum values of von mises stress obtained werefor egg crate with handles. For HDPE crate, the maximum value was 160.76 MPa MPa which was well below the value of young modulus for HDPE. Similarly for Polypropylene the maximum value was 68.15 MPa. The values of Von Mises stresses obtainedhigherfor the crateswhen lifting handles were due to the contact areas between handles and crate. When the simulation of egg crate without handles was done, the end contours of the egg crate were kept fixed while for simulation with lifting handles applied, the faces of handles in contact with crate were kept immovable.It may be observed from the results table (Table 1) that values of stresses obtained were less for the designed egg crates. The reason for the same may be attributed to increased thickness of designed egg crates. Stress values were found to be more at various regions in the case of egg crates with handles. These regions were at the contact periphery of crate surface and handle surface. Further the stresses obtained were almost same in case of conventional egg crates while there was an appreciable difference between the two materials when simulation of egg crates with handles was performed. The reason may be the difference in the properties of the two materials used in the present study.

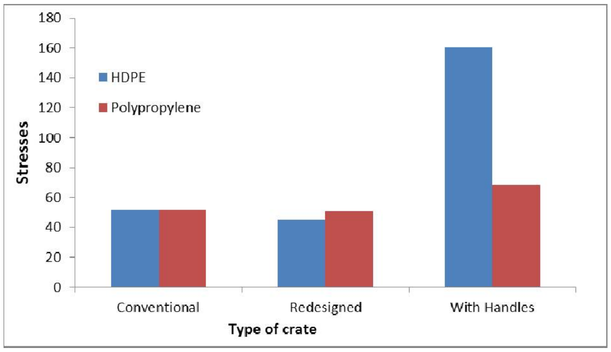

Fig 4. Von-Mises stress distribution for three different crate.

The values of deflection in X, Y, and Z directions obtained using Inventor Professional software for the six different types of egg crates simulated in the present research have been shown in Figure 5.

The values of deflection in lateral direction (X and Y) were far less than the deflection about on the Z-axis i.e. in the direction of applied load. A comparison of the deflection values obtained for the egg crates simulated in the present work has been shown below (Figure 5). The values of deflection were found to be higher for conventional egg crates when compared with other types of egg crates studied. As the load applied was in Z-direction, the deflection obtained was more in Z-direction for the egg crates made up of the two types of materials. The difference in deflection obtained in the X and Y-axes was appreciably less in contrast to the deflection in Z-axis. Deflection in redesigned egg crate obtained was significantly low compared to deflection observed in a conventional crate. The increased thickness provided in the regions where the deflection was more caused the decrease in the defection in the direction of the applied load.

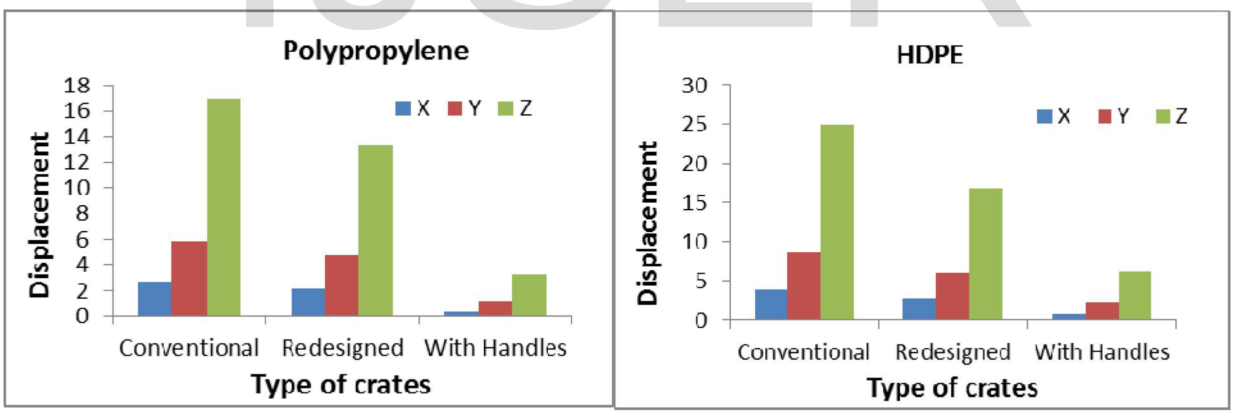

Fig 5. Comparison of deflection between crates

Further it may also be observed that deflection in the egg crates with handles wassignificantly less than the conventional egg crates. As the redesigned egg crate appreciably reduced the deflection in all the three X, Y, and Z directions, breakage of eggs due to deflection causing compression of eggswhile lifting the egg crates was almost eliminated. Therefore from the results it can be concluded that the egg crates with handles may be used to avoid breakage of eggs. Due to the increase in thickness at regions where the deflection was more, a slight increase in the mass of the egg crate was observed as shown in Figure 6.

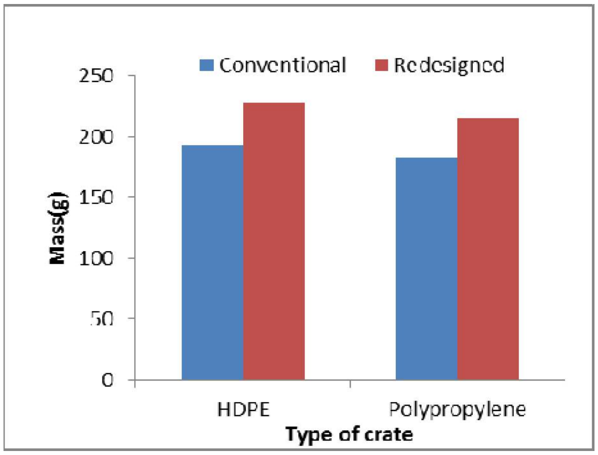

Figure 6: Comparison of Mass between crates

Mass of redesigned crate was more than conventional crate by 32 grams using polypropylene while there was an increase of 35 grams in an egg crate made up of HDPE. Though the increase in the mass of the material may increasethe cost of crate, it may not be significant as it will result in great savings due to the elimination of breakage during lifting and carrying.Table 2 showed the effect of using handles on the RWL and LIduring lifting. There was an increase in RWL using handles due to the improvement in the coupling multiplier. The coupling multiplier was 0.90 when the lifting was done without handles which was increased to 1.0 for egg crates with handles. A reduction in LI was also observed for egg crates with handles. Hence it may be concluded that using lifting handles, a worker may lift more number of egg crate

5. Conclusions

Present research made a simulation study to redesign an egg crate to eliminatebreakage of eggs and help worker to perform his task efficiently. Based on the findings of the study, following conclusions may be drawn

(i) Use of handles while lifting egg crates may eliminate breakage of eggs.

(ii) Use of handles on the egg crates has a positive significant effect on RWL and LI for lifting a stack of crates.

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