

Design, Analysis And Selection Of Shock Absorbing EPS Foam Packaging Material

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Abstract: This study is done by the company Whirlpool of India Limited, situated at Ranjangaon MIDC, Pune. The company is facing the problem regarding to packaging system. In December 2018, 265 Litre Whirlpool refrigerator product was found in damaged condition at e-commerce company amazon's ware house. Dents were found on the door and outer wrapper of refrigerator. Also EPS protection were found in damage condition. Hence, this product has been blocked for selling by amazon Company. Also amazon is demanding for ISTA certification of above mentioned product for further selling process. After root cause analysis it is clear that EPS currently used is failing to absorb energy dissipated during impact. So, it is needed to select EPS (thermocol) with more strength, energy absorption capacity and cushioning effect and changes in packaging protection post. Strength of the EPS is mainly function of granular size, density, heating temperature and pressure of the steam. Mechanical properties of existing and new material will be compared after carrying out tensile test and compressive test as per ASTM standards. FEM analysis for structural testing has been done in ANSYS Workbench

Index Terms: Cushioning effect, Energy absorption, Impact analysis, Packaging test, EPS foam, ISTA testing, Stress strain curve for EPS, Structural testing, Stress analysis of EPS

1. INTRODUCTION

Mostly expanded polystyrene (EPS) foam, expanded polyethylene (EPE) foam, expanded polypropylene (EPP) foam, honeycomb are the cushioning material used for packaging and protecting. EPS is scientific name of the thermocol. As per the refrigerator's packaging is concern, In India EPS foam is the best material available. EPE is the chip but hard to mould where as EPP can be molded but costly and need to import and the problem with the honeycomb is that it can't sustain the pressure in the clamping test, it has low cushioning effect. EPS with various densities are used in the refrigerator packaging. In this study, EPS with 20 Kg/m³ density is used for protection, Further energy absorption capacity is calculated for EPS with density 12, 17, and 22 Kg/m³. Certain experimental tests like water absorption test, compressive strength test, flexural strength test, tensile test and triaxial test has been carried out by Y.J.Baju [1]. The test setup is done as per ASTM standards. He took three samples of EPS geofoam each of density 12, 15 and 20 kg/m³. He found that The flexural strength of EPS geofoam increases with the increase in density. Higher density test specimen failed at lower deformation due to increase in the stiffness with an increase in density. FEA of EPS is done under multiple compressive loading and unloading by Umud Esat Ozturk et. al [2]. ABAQUS AND LS-DYNA are the software used. Results of FEA packages ABAQUS and LS-DYNA are compared to compression test results and cushioning diagrams for multiple loadings. A cushioning diagram shows how the packaging material of a considered thickness behaves at different impact loading conditions. Uniaxial compression tests, uniaxial tension tests and three point bending tests are performed by the Ninghan Tang et. al [3] to find the mechanical properties of polystyrene foam (EPS). Author found that EPS exhibits a ductile to brittle transition when the loading mode changes from compression to tension. The digital image correlation

(DIC) technique is used to measure the strain distribution. In the study of Wensu Chen, Hong Hao [4], static and dynamic compressive and tensile test data of EPS with density 13.5 kg/m³ and 28 kg/m³ at different strain rates are studied. The dynamic strength, Young's modulus and energy absorption capacities of the two EPS foams at different strain rates are found and presented in the paper. The test setup for compressive test and tensile test are done as per ASTM standards. It was found that the EPS static strength and Young's modulus increase with its density. High density EPS also has higher energy absorption capacity than low density ones. The EPS compressive strength increases rapidly with the strain rate when the strain rate.

As per the packaged product is concern, they has to go through ISTA testing sequence which consist of Environmental Conditioning, Stacking test for vertical compression & stability, free fall drop test, vibration testing with load, inclined impact testing, Puncture test, dragging test. These testing consider all aspects of transportation and handling. So company has the data from the field or different ware houses through the country. Now for further analysis, those data will be replicated in the lab to convert it into engineering problem. Also we have carried out test to fail of the product as per ISTA standards, so that we can understand the failure limit of our product, whether it is passing in ISTA testing, if not which factor should be improved etc. Weight, dimensions and testing procedure varies from product to product. In this paper all the calculations for packaging test are carried out for 360 liter product. In this paper we will see step by step how the sequence of packaging test is carried out as per ISTA standards, maximum impact produce in the field during handling product, then energy absorption capacity of current EPS foam used and optimization of packaging post. The following test sequence need to conduct as per ISTA standards for the any product approval. Also, while testing the any product there is common terminology need to identify faces on the product with damages. Face 5 stands for the front door. Other are shown in following fig. ().

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(This information is optional; change it according to your need.)



Figure 5. Ball impact testing apparatus Position to heat the ball on product

product life cycle. Overall it helps to check the design capability at life including light switch operation, gasket seal integrity, door lock operation & door closure function during the specified number of operating cycles. The door sag should not be more than 2 mm.

2.2 Experimental Investigation on ISTA Test sequence:

This is how the complete test procedure as mentioned in chapter 4 required to follow for the product approval before launching to market. Out of the above mentioned tests, Ball impact, inclined impact and drop test are severer as compared to other. Hence test to fail has been carried out for them only. Test to fail is carried out to find out limit of failure of the product in that particular test. Now we will discuss it as follows

2.2.1 Observation noted for ball impact test:

In ball impact test, 12 impacts on each face are supposed to make starting from 20Nm energy up to the limit of its failure. Following is the table in which all observations are noted. By this process we hit on EPS covered and uncovered area. Also Honeycomb is alternate material to EPS foam which is easily available and tested for ball impact. But it failed to sustain impact energy of 20Nm. Hence it is better to go with EPS foam.

6. VIBRATION TEST:

The vibration test shall be carried out by placing one packaged appliance, complete with its accessories, on the vibration table equipment in order to simulate the means of transportation. The test has to be carried out with load. (load at the top is not applicable in case shipment is intended in single stack)

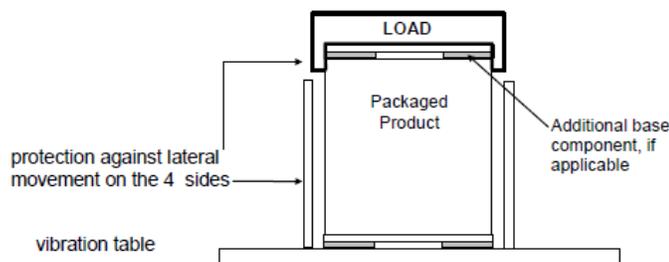


Figure 6. Position of product for vertical vibration

The components must remain tightly fixed / in place after the test (screws, panel, sheets, bins, other internal/ external parts.)

7. BALANCING DROP TEST:

This test is carried out on the above 2 sets of packaged samples, to simulate the shocks caused by the unloading horizontally transported appliances, from the means of transport. The packaged appliance, placed horizontally on the floor is raised (from one side) 40 cm and then dropped on the allowed faces of the packaging in the following way.

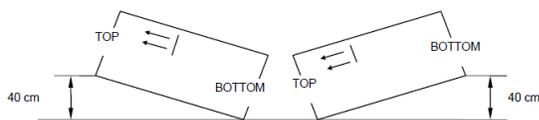


Figure 7. Position of Product for Balancing Drop Test

8. DOOR OPERATION TEST:

Door operation test is not a part of packaging test but after passing through the sequence of the packaging test the door loosening or seal loss problem might arise. Hence to check the ability of the refrigerator door to endure the 50,000 number of operating cycles were carried out. This also inspects if cabinet liner is damaged due to the forces set up by the numerous door operations. Also to find the sag of the doors over the



Figure 8. Ball impact testing

Conclusion: Product is passing at the area which is covered with EPS, but failing at non-EPS coverage. Also it is passing at front door but failing at back and sideways.

FRONT-WOIL				
STANDARD	Location	WOIL STD	PASSING AT	TEST TO FAIL
As per WOIL Std locations	5	20	51	64
	5b	20	51	64
	8	20	51	64
Added location for test to fail	4	20	38	50
	4a	20	38	50
	7	20	38	50
	6	20	38	50
	6c	20	38	50
	9	20	38	50

Note: All the values are in N-m i.e. impact energy

Figure 9. Ball impact observation noted for different location at front door.

Also observation for side wise hitting are as follow

SIDE-WOIL			
Location	WOIL STD	PASSING AT	TEST TO FAIL
5	20	38	43
5b	20	38	43
8	20	38	43
4		<19	19
4a		<19	19
7		<19	19
6		<19	19
6c		<19	19
9		<19	19

Figure 10. Ball impact observation noted for both RHS and LHS side

Table 1. Observation for inclined impact test.

INCLINED IMPACT - DUMMY					
ORIENTATION	POSITION / REPETITION	HAZARD BLOCK	Impact energy	Carton damage	Product damage
FACE 2	2.1	YES	1370	No(impression)	No
	2.2	YES	1370	No(impression)	Yes
	2.3	YES	1370	No(impression)	No
FACE 4	4.1	NO	1370	No(impression)	No
	4.2	NO	1370	No(impression)	No
	4.3	NO	1370	No(impression)	No
FACE 5	5.1	NO	1370	No(impression)	No
	5.2	YES	1370	No(impression)	Yes
	5.3	NO	1370	No(impression)	Yes
FACE 6	6.1	NO	1370	No(impression)	No
	6.2	YES	1370	No(impression)	No
	6.3	NO	1370	No(impression)	No

2.3 MAXIMUM IMPACT ENERGY PRODUCED IN FIELD

2.2.2 Observation noted for free fall drop test:

As per ISTA standards, for free fall drop test, product should be drop from 32 inch height, whereas, as per company standards drop height is less, hence this is generating more impact energy.

Conclusion:

Compressor mounting plate situated at backside bottom area was found minor bent. And EPS base protection found in minor damaged condition in short no dents on the wrapper and the door.

2.2.3 Observation noted for inclined impact test:

Hazardous block is added on platform as shown in following photo to make test more sevier. Block is held tightly at 1/3rd, middle, and 3/4th position and product is impacted.

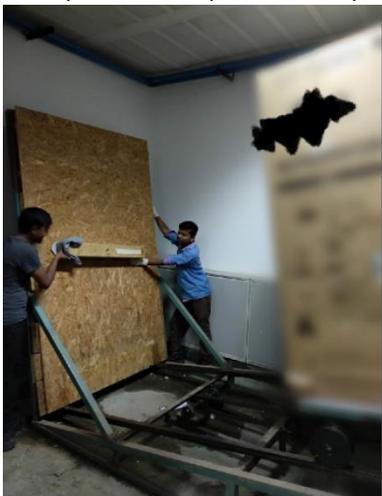


Figure 11. change image WPL

Conclusion:

Minor product damage was found on face five that is at door edge and side edge. The observation is noted as follow, In this way, ISTA testing sequence is carried out on the product where product is failing at all three sevier test. This is because EPS currently used as a protection post is getting damage and failing to absorb energy during impact also it was observed that EPS covered area was less in ball impact test, this resulted in product failure at lower energy. Now, as per the methodology we will find the impact produce in the field in all three tests.

2.3.1 Energy produced during ball impact test:

Ball impact test platform is compared with simple pendulum geometry, By Applying energy conservation equation, Total Energy before impact (1) = Total energy after impact (2), i. e. $KE_1 + PE_1 = KE_2 + PE_2$, As initially body is in rest condition Kinetic energy will be zero and at final position, as the body is in moving condition potential energy will be zero. Hence, $PE_1 = KE_2$ i.e. $mgh = \frac{1}{2}mv^2$ Where h is the height from the intial position of the pendulum, v is final velocity after impact and m is the mass of the ball. As per specification impact energy generated in this test is 20Nm. but considering the factor of safety, let say our prouctd should sustain 40Nm impact energy.

2.3.2 Energy produced in free fall drop test:

By Applying energy conservation equation, $PE.1 + K.E.1 = P.E.2 + K.E.2$, Where, Suffix 1 and 2 are for initial and final position of the product for Potential Energy and Kinetic Energy respectively. Hence, in free fall drop test Hence, Product under investigation with weight 75 Kg has impact energy equal to 603.31 Nm.

2.3.3 Energy Produced during inclined impact test:

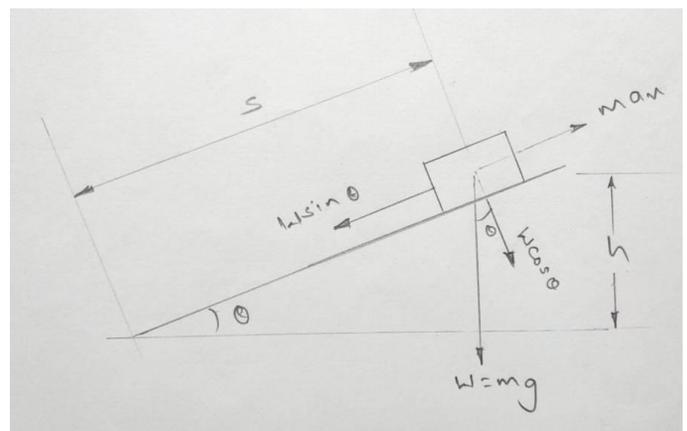


Figure 12. FBD for inclined impact platform

$F_x = ma_x$
 After resolving the component,
 $\sin\theta = W/g a_x$,
 $a_x = g \sin\theta$.
 Using kinematic equation, $v^2 = u^2 + 2a_x s$

Where, u is initial velocity = 0 m/s,
 v is final velocity and s is inclined distance covered on platform. From geometry of the body,
 $\sin \theta = h/s$ (ii)

From eq. (i) and (ii),

$$v^2 = 2g \sin \theta * s$$

where h is height at which product is placed initially, θ is angle of inclination of plane.

Hence, $v = 3.797$ m/s

Now, calculating energy generated during impact, i. e. addition of both linear speed and rotational speed of the body,

$$E_{\text{Total}} = KE_{\text{Trans}} + KE_{\text{Rot}}, \text{ on solving } E_{\text{Total}} = 1081.20 \text{ Nm}$$

So, from all three sevier test we can conclude that maximum impact energy produce in the field is 1081.20 Nm. Now, next thing to calculate is whether the existing EPS protection post design have this much energy absorbing capacity. For that we have conducted tensile and compression test as per ASTM standards.

3. TENSILE AND COMPRESSIVE TESTING OF EXISTING EPS SAMPLE AS PER ASTM STANDARDS

3.1 Tensile Testing:

Tensile test is carried out on 20 Kg/m³ density sample according to ASTM standard D638 – 14 used for plastic materials. Tensile test is carried out to check are these properties matching with suppliers specification. Properties for existing EPS sample is as follow,

- Modulus (Automatic Young's)[MPa]= 790.96
- Energy Absorption per unit Volume(Nm) = 1.26
- Tensile stress at maximum load [MPa]= 0.18

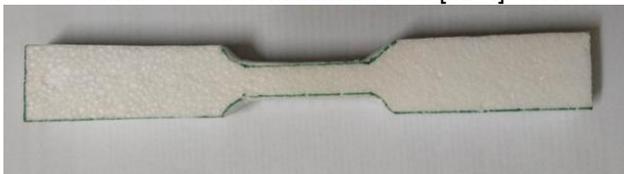


Figure 13. EPS sample for tensile test



Figure 14. EPS sample with under tensile testing

3.2 Compression Test:

As in all the three conditions of standard testing that is in incline test, drop test and ball impact test, EPS is going through the compression. Hence, Compressive test were carried out on existing sample as per ASTM Standard D695 - 15. These are the standard test method for finding

compressive properties of plastics. From compressive test energy absorption capacity were calculated for given specimen. Dimensions are considered as per standard. From cushioning effect of EPS 50% of compression is considered.

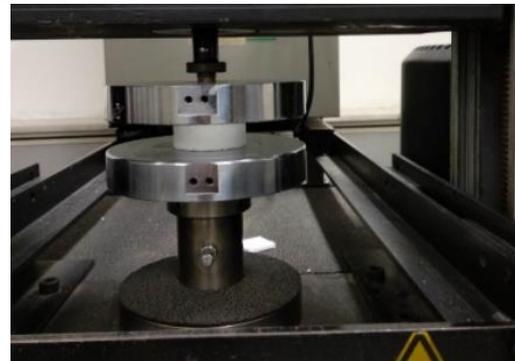
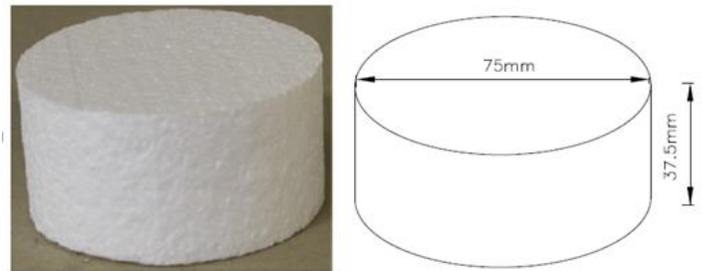


Figure 15. sample for compression test with dimensions

Energy generated per unit volume for given sample is the area under stress strain curve of compression test. As the strain energy for 56037 mm³ of sample is 2.74 Nm. we can find the strain energy for the volume facing during impact lab test simulation. Volume of the protection post facing impact is 20332000 mm³ and energy absorbed by this much volume is 994.15 Nm. As Inclined impact test consist of maximum amount of energy release i. e. 1081 Nm. So it is expected to absorb this much energy by 20332000 mm³ of sample. But, 994.15 Nm is less than 1081 Nm. Hence it is needed to develop the design of protection post that will cover more area or further experimentation need to carry on EPS sample with different densities, so that they will give more strength and energy absorption capacity more than 1081 Nm.

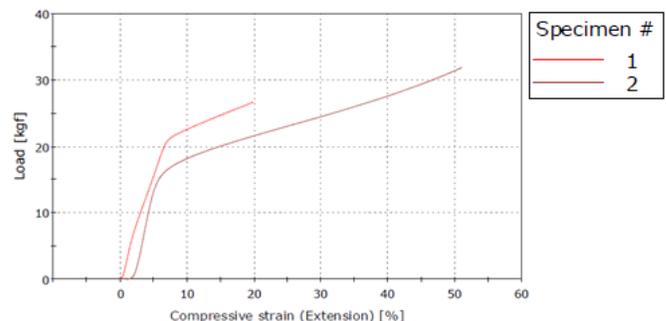


Figure 16. Load vs strain curve for compression of EPS 20. Specimen 1 and specimen 2 of EPS 20 has been compressed to 20% and 50% respectively to check linearity of sample and to insure whether curves are matching or not.

Now, compression test has been done on EPS with different densities 8, 12, 17, 22 Kg/m³ to find the strength and energy absorption capacity. For the simplicity let us call them as EPS

8, EPS 12 etc. As we concluded from the above session that next selected EPS should have either higher energy absorbing capacity or there should be change in the design of protection post, so that it can cover more area which will absorb energy during impact. Now below is the graph for the compression test of EPS sample with various densities.

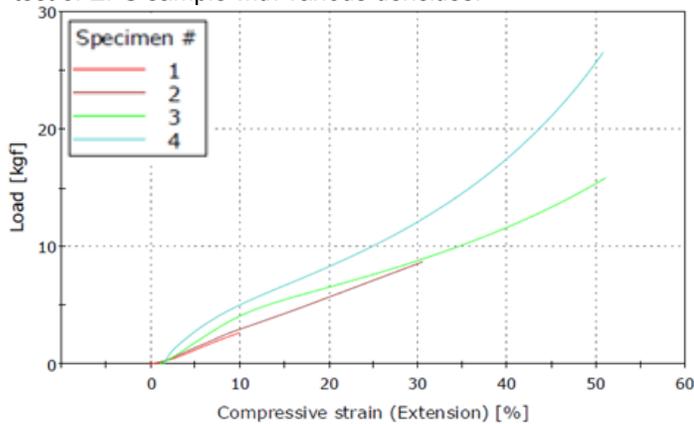


Figure 17. Load vs strain curve for EPS 8 and EPS 12

Specimen 1, 2 and 3 are of EPS 8 and are compressed for 10, 30 and 50% to check the linearity of the graph. Sample 4 is for EPS 12. Now we will see the graph of EPS 17 and EPS 22 as follow,

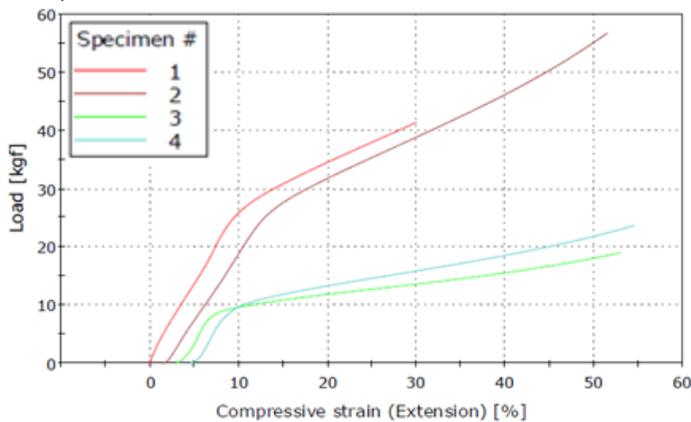


Figure 18. Load vs strain curve for EPS 17 and EPS 22

In the above graph, Sample 1 and 2 belongs to EPS 22 where as sample 3 and 4 belongs EPS 17. Sample 1 is compressed for 30% and other is compressed for 50%. Hence for 50% compression their compressive strength and strain energy generated are noted below. From above table it is clear that while compressive strength and strain energy for EPS 17, 20 and 22 are very close to each other. In order to maximize strain energy it is needed to add more coverage area and move to EPS 22 but cost is the factor need to consider. Cost of EPS is totally depending upon weight. Hence from obtained properties FEM analysis on EPS 17 has been done to check whether it can withstand for dynamic and static field condition.

corresponding density

Sr. no.	Density	Compressive strength	Strain energy produced
	Kg/m³	MPa	Nm
1	8	0.07	1.1
2	12	0.11	1.65
3	17	0.2137	2.50
4	20	0.24	2.74
5	22	0.2620	2.86

4. PACKAGING OPTIMIZATION:

Two major things have been come until now that is from quality point of view, it is needed to increase surface area coverage so that is will protect the product from impact in the field and second from cost point of view that is about selection of EPS with particular density which will give proper impact energy absorption capacity.



Figure 19. Impact on refrigerator wrapper instead of EPS protection post

4.1 PFEM ANALYSIS OF BALL IMPACT TEST:

As we have seen in table 2 that EPS 17 and EPS 20 have negligible changes in the strength and properties we can go for EPS 17 by providing sufficient protection area. In order to increase protection area EPS plane sheet will be added. In session 2.2.1 we have seen that product is failing at 19Nm energy in ball impact. Hence, FEM analysis on ball impact test has been carried out in explicit dynamic where ball has been placed at a distance of 5mm before hitting the EPS protection. And the speed of 3 m/s is given to the ball. If it compress the EPS 17 less than 50% then our FEM analysis will be considered as a successful. Also stress induced on the door wrapper should be far less than yield strength. Material assign for the ball is structural steel with the mass of 4.5 Kg. and material for the wrapper is galvanized iron. Where simulation is made such that ball is going to impact on the wrapper through the EPS protection. EPS dimensions are 300 x 300 x 20 mm. Geometry of the design is as follow,

Table 2. Compressive strength and strain energy for

generated of 15.826 MPa which is far less than yield strength of wrapper material.

RESULTS

Figure 20. CAD for ball impact through protection post

BOUNDARY CONDITION:

The door wrapper is fixed at the corner and ball impact is done at 3 m/s. The material properties for EPS 17 has been assigned as that of got in compression test.

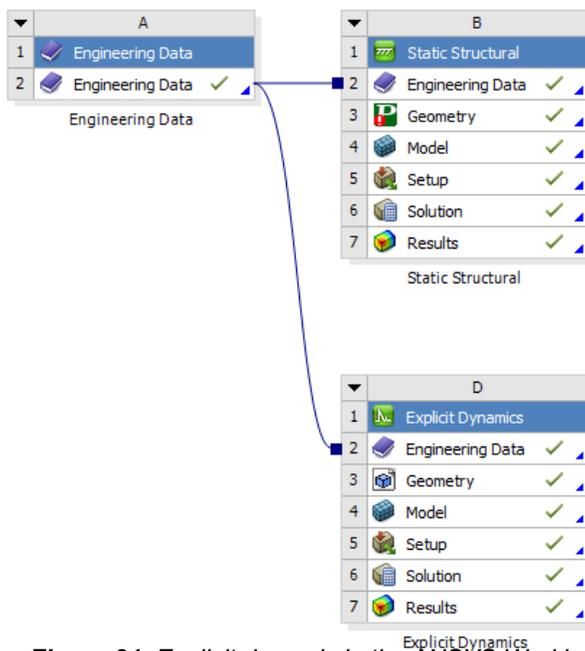


Figure 21. Explicit dynamic in the ANSYS Workbench

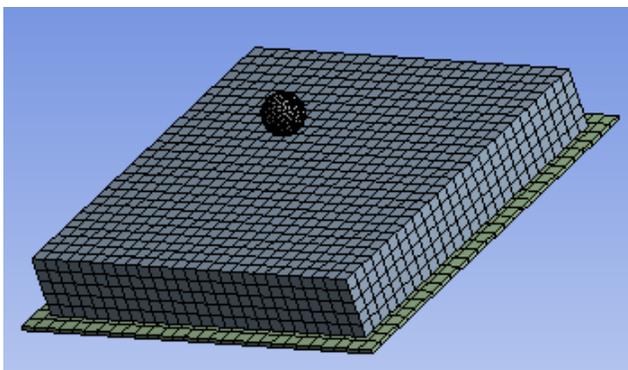


Figure 22. Meshing on ball, protection post and wrapper

Results obtained are as follow,

From the above simulation it is clear that EPS 17 with thickness of 20 mm can sustain the point impact of 45Nm with the maximum deformation of 5.967 mm and maximum stress

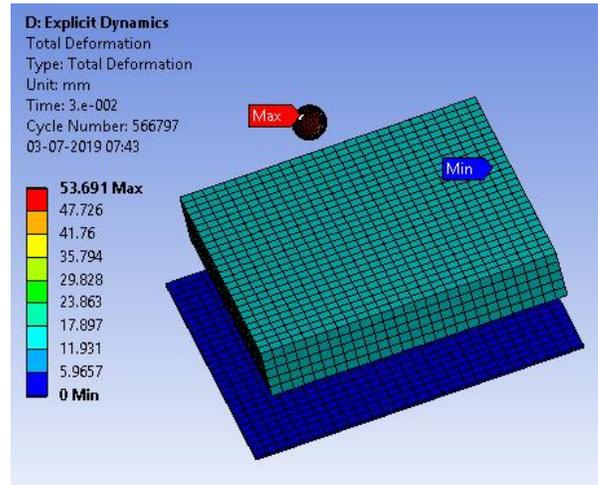


Figure 23. Deformation of EPS protection post

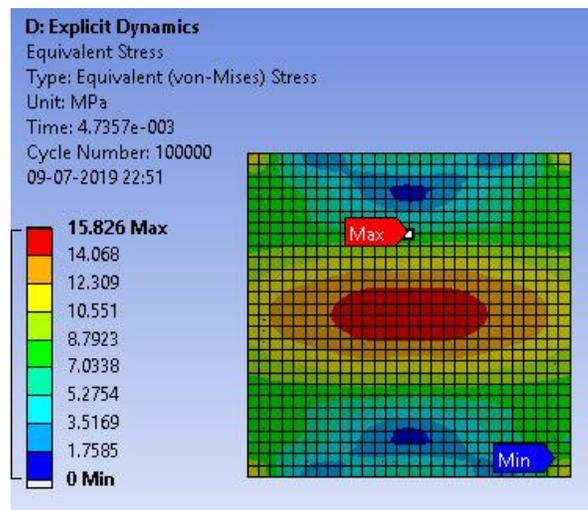


Figure 24. Maximum stress generated on wrapper

4.2 TOP POST OPTIMIZATION:

Currently top pad is fully covered. Basically compression test is carried out for verifying top EPS protection design and stability of stacking. It should sustain the applied force and should not compress for more than 20 mm as per ISTA standard. Here topology optimization is carried out to for checking the area affected by stress. As the blue shaded area is least affected, we have the scope to redesign top split. As the top post is resting on the refrigerator it has a fix support at one end and the force of 5150 N acting on opposite face as shown in figure.

BOUNDARY CONDITION:

Weight of 525 Kg is supposed to be acting on the refrigerator. Hex meshing has been done with mesh size of 2 mm. mesh quality kept as a fine.

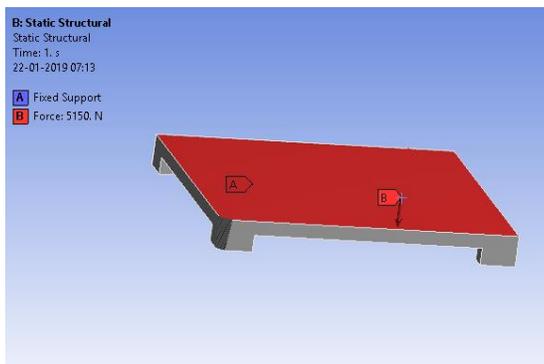


Figure 25. TOP pad with boundary condition

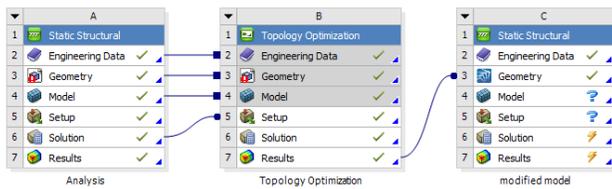


Figure 26. Steps in topology optimization

So, after topology optimization it is clear that top EPS protection can be split with near about 50 % mass reduction into two halves. Blue shade shows minimum stress concentration area.

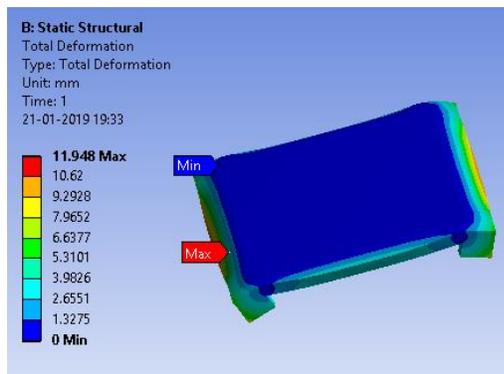


Figure 27. Results for total deformation

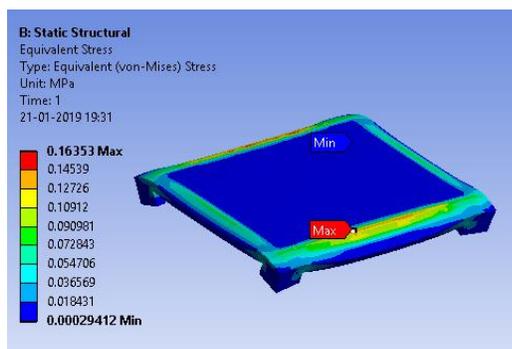


Figure 28. Results for equivalent von-mises stress

So, after topology optimization it is clear that top EPS protection can be split with 50 % mass reduction into two

halves. New design for right hand side and left hand side EPS protection are as follow.

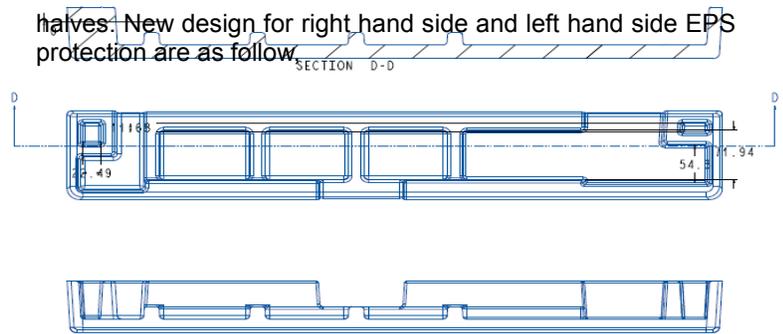


Figure 29. Top split protection



Figure 30. Prototype of redesign top protection

4.3 Reduction In The Height Of Corner Post:

As the data from the field suggests, maximum percentage of the dents are found on the RC door and at bottom side of the wrapper. Hence cost of addition of center post can be balanced by reducing all corner post height by 30%. While moving the product in the ware house, rangers (clamping and moving vehicle) clamps total 8 product at a time. Hence, feasible of clamping in the warehouse movement is checked. So, maintaining 70% corner post is possible without any risk.

5. RESULTS AND DISCUSSIONS:

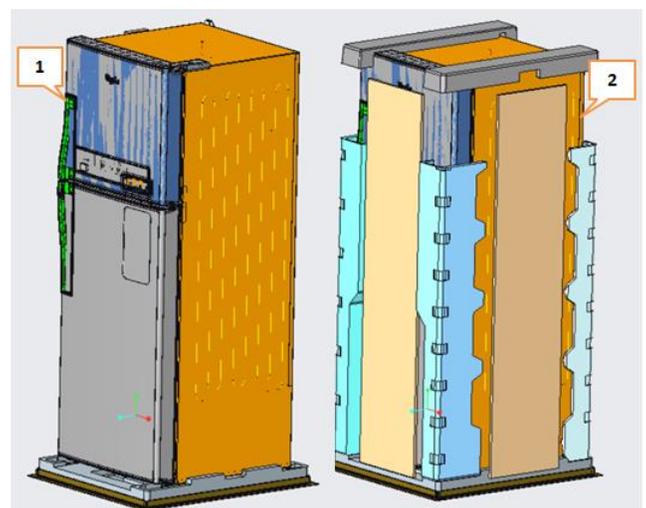


Figure 31. CAD Model of the product (1) without and (2) with packaging protection post

1. Maximum energy generated during the impact in the field is

1082 Nm where we achieved it by increasing the area of EPS facing impact by adding front center post.

2. From costing point of view EPS 20 with strain energy 2.74 Nm can be replaced by EPS 17 with low strain energy 2.50 Nm need to provide more surface area coverage.

3. Addition of full coverage of center post will change the volume of protection post from 2,03,32,000 mm³ to 2,48,00,000 mm³. With this increase in the volume, sufficient energy absorption capacity of 1106.50 Nm is achieved.

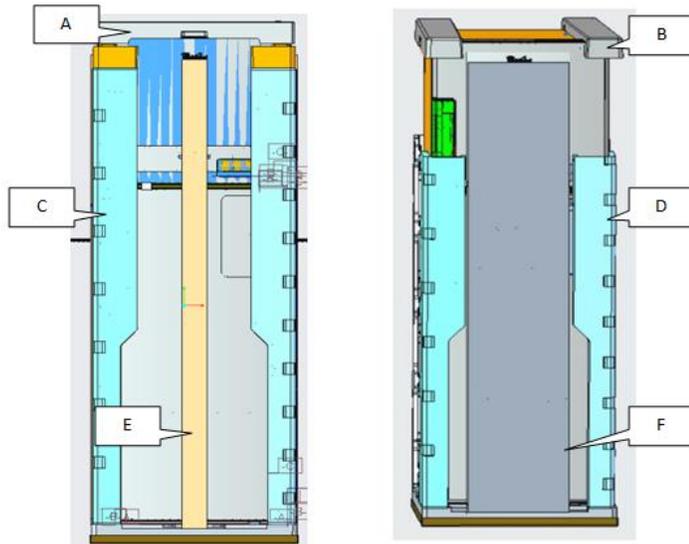


FIGURE 32. EXISTING AND PROPOSED DESIGN FOR EPS PROTECTION POST

Modification of protection post is as follow,

A to B : Full top protection to split top protection

C to D : Full corner post to 70% covered corner post.

E to F : Narrow center post to full covered center post.

6. CONCLUSION:

In FEM analysis EPS 17 with thickness 20 mm can sustain 45 Nm of energy, where as in practical, EPS 17 with available thickness 15 mm also sustain up to 45 Nm of energy. Hence critical thickness for front center post can be decided between 15 to 20 mm. EPS 12 can be used for front center post which can sustain 30Nm of energy.

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