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ROBUSTNESS AND PACKAGING EVALUATION OF WASHING MACHINE IN REAR INCLINED IMPACT SIMULATION

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Abstract - *A commercial washing machine comes under the category of white goods and is intended for heavy and frequent use. During the transportation there are various unavoidable accident such as rear inclined impact which greatly affects the critical components of the machine such as rear upper tray, rear lower tray, c-shaped cabinet etc. Analysis of these components becomes mandatory so as to evaluate the damages caused by the impact. Packaging elements are employed to avoid damages and ensure their safety. In this work expanded polystyrene (EPS) and multi grade paper corner protection pads are being used as packaging elements for an LG commercial top loading washing machine. The aim of this study is to evaluate the ruggedness and robustness of the machine components and packaging elements by performing crash analysis. Emphasis is given only to the rear part of the machine. Geometric model is created using CATIA V5 and later meshed using HYPERMESHv11. Appropriate boundary conditions, load conditions, material properties are assigned to the model and crash analysis is done using Ls-Dyna. Contour plots are obtained for the important components depicting max stress and strain. Experimental analysis is performed according to ASTM D880 standard. The acceleration data is obtained from the simulation and is compared with the experimental data.. No major risk was observed on the rear components. The acceleration data obtained from both the simulation and experiment are in co-relation with one another.*

Key Words: CATIA V5, HYPERMESH v11, EPS, Ls-Dyna, ASTM D880.

1. INTRODUCTION

A commercial washing machine comes under the category of white goods and is intended for heavy and frequent use than a household washing machine. They are built with large easy-to-open covers and are installed in publicly accessible Laundromats. The capacity of commercial washing machine ranges from 20 to 120 kg because of which the transportation and packaging employed is different from that of consumer washing machine. Various types of unavoidable accidents occur during the transportation of the machine. Rear inclined impact is one such type of unavoidable scenario observed during the transportation of the product from regional distribution center (RDC) to Local distribution center (LDC) or from Local distribution center (LDC) to retailer/consumer [1].

In this paper, crash analysis of an LG top loading commercial washing machine along with its packaging is subjected to rear inclined impact simulation and its crashworthiness and robustness is evaluated [1,2]. The study only includes the effect of the impact on the rear part of the machine and its respective components.

1.1 Transportation and Packaging

Transportation plays a very important role in the distribution and success of a product. There exists a supply chain for the distribution of white goods to optimize the distribution process and deliver the product form factory to the consumer. During this distribution chain various types of damages occur and necessary precaution must be taken for the safety of the product.

Packaging of commercial washing machine plays a very important role in preventing the damages that can occur to the commercial washing machine due to rear inclined impact scenario.

Some of the most important packaging materials used to avoid or reduce the damages caused by the rear inclined impact are as follows:

Corner protection pads: These provide stability and protect the machine against external force applied during transportation and loading. It includes a cushion portion configured to correspond to a corner of the washing machine. [3]

Expanded polystyrene (EPS): It is foam based polystyrene plastic. It is employed because it is lightweight, durability and insulating properties [4]. In this study EPS are used as tub insert and bottom protection pads.

2. REAR INCLINED IMPACT SIMULATION

In this study, the machine is subjected to rear inclined impact simulation which is in accordance with the ASTM D880 standard [5].

2.1. Assumptions

- Simulation is done only for loading condition and hence stress and deformation are only for loaded condition.

- High stress near sharp corners and bolt holes are neglected due to stress concentration effects

2.2. Procedure

- Position the packaged product such that its rear face is impacted.
- Rotate the product at 10^0 with respect to the ground. Refer Fig-1.
- Create one infinite rigid wall on the bottom of the product (1mm below the bottom face) and other rigid wall on specified face of the product (1mm offset from the face) to represent the backstop on which it is impacted.
- In the Fig-1, left hand side impact is shown [5].

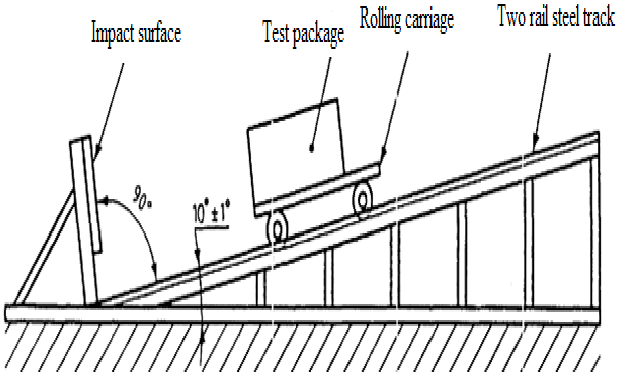

Fig -1: 2D view of incline plane tester

2.3. Loading Condition

- Initial velocity of 1828.8 mm/s is applied to the full product and package assembly. Both the horizontal and vertical velocity components are considered. Horizontal velocity of 1800 mm/s and vertical velocity of 317 mm/s is applied to the full packaged product.
- Gravity load (G=9810 mm/s^2) is applied to the full product in vertical direction.
- Multiple impact effect on the EPS material is also included in the simulation because during testing all four sides are impacted simultaneously [5].

3. FINITE ELEMENT MODELING AND SIMULATION

Crash analysis using Ls-Dyna was performed to check the robustness and ruggedness of the rear components of the machine. A brief description of the model created and meshed is explained in the following section.

3.1. Geometric Modeling

A geometric model of a top loaded commercial washing machine was created using CATIA V5. Fig-2 shows the geometric model created.

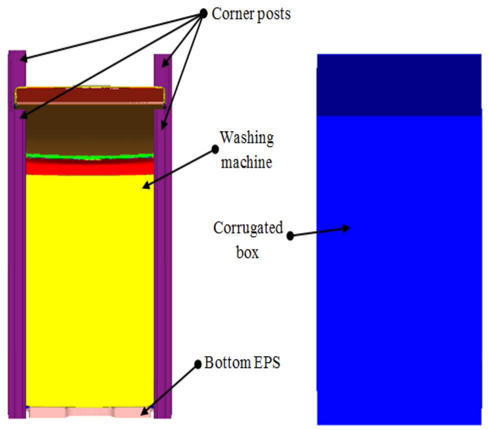

Fig -2: Geometric model of top loading washing machine

3.2. Meshing

The geometric model created was meshed using HYPERMESH v11. Firstly 2D meshing was performed on various components using only first order appropriate elements such as quad-8, tria, R-tria etc. Later the 2D mesh was converted into 3D mesh resulting in shell, tetra or hexa mesh depending upon the 2D elements. Fig-3 shows the meshing performed on the rear component.

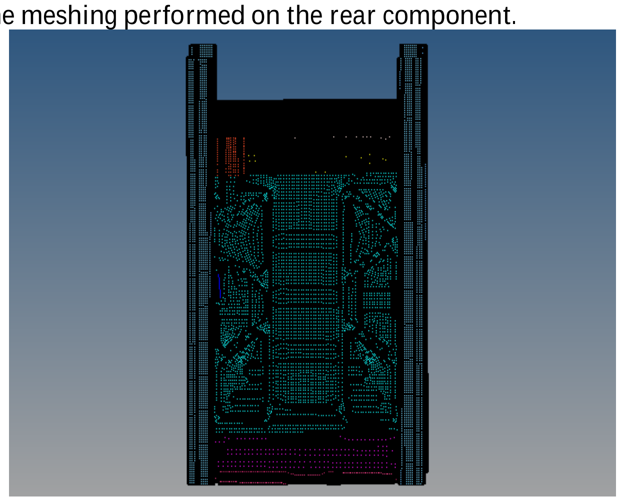

Fig -3: Meshed rear part of the machine

3.3 Crash Analysis

The ability of the component to absorb energy to prevent the damages in the event of an accident is referred to as crashworthiness and its analysis is called crash analysis. In this study the rear face of the machine is being impacted to an infinite rigid wall and the crashworthiness of the essential rear components is being performed using Ls-Dyna.

Proper boundary conditions, load conditions, material assigning, material properties, control cards and contacts were given to the meshed model in Ls-Dyna such that the simulation is similar to the real life scenario.

The contacts given to the meshed model are

- *CONTACT_TIED_SURFACE_TO SURFACE_OFFSET

- *CONSTRAINED_EXTRA_NODE_NODE
- *CONSTRAINED_EXTRA_NODES_SET
- *CONTACT_AUTOMATIC_GENERAL
- *CONTACT_AUTOMATIC_SINGLE SURFACE
- *CONTACT_AUTOMATIC_NODES_SURFACE
- *CONTACT_INTERIOR

Lastly the control cards used in the simulations are

- *KEYWORD_ID
- *CONTROL_TERMINATION
- *CONTROL_TIMESTEP
- *CONTROL_SHELL
- *CONTROL_HOURGLASS
- *CONTROL_SOLID
- *CONTROL_CONTACT
- *CONTROL_PARALLEL
- *CONTROL_OUTPUT
- *CONTROL_ENERGY
- *CONTROL_ACCURACY
- *CONTROL_SOLUTION
- *DAMPING_GLOBAL

4. RESULTS AND DISCUSSIONS

The aim of the work was to develop and verify an FE model which can be used for further studies and application. Following section discusses the various results obtained from both the simulation and experiment.

4.1. Simulation Results

Simulation was performed using Ls-Dyna and contour plots depicting stress and strains were obtained. Following are the contour plots of the essential rear components after the impact.

1. Rear Panel

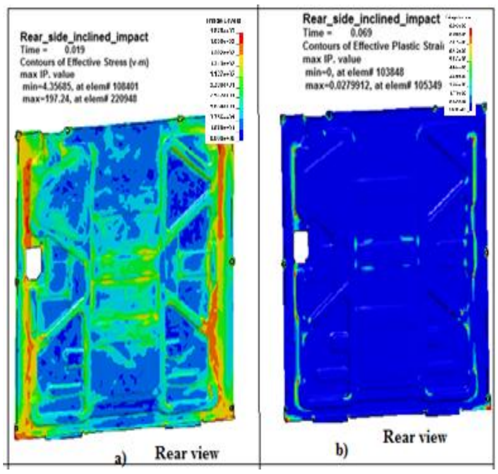

Fig -4: Rear panel: (a) Max Von mises stress (b) Max Principal strain

2. Bottom EPS

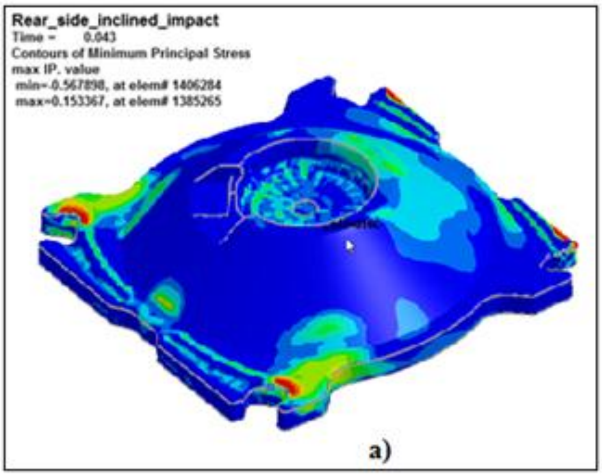

Fig -5: Bottom EPS (b) Energy absorbed by the bottom EPS

Similar to the above components, contour plots for other essential rear components were obtained. Following table-1 compares the different parameters such as maximum von Mises stress, maximum stress etc. from the contour plots of various components. From the values obtained we can estimate the risk factor of that component.

Table -1: Comparison of contour plots.

Part Description	Yield Strength (Mpa)	Max von Mises stress/Max Principal stress	Max Principal strain(%)	Risk Factor
Rear assembly-Upper tray	71.3	53.18	0.47%	No major risk
Rear assembly-Lower tray	71.3	33.59	0.5%	No major risk
Cabinet	227	242.22	1.8%	Major risk(bolted connection
Rear panel	169	197.24	2.79%	Major risk(bolted connection
Bottom EPS		0.177		
Tub insert		0.014		

4.2. Acceleration Data from Experiment

An accelerometer is an instrument used for measuring the acceleration of a moving or vibrating body. In this experimental setup tri-axial accelerometers are used in lower tray and valve body to measure the gravitational force occurring during the impact. Fig-7 shows the tri-axial accelerometer placed valve body.

Fig -6: Tri-axial accelerometer on valve body

Fig-7 shows the graph obtained from the accelerometer placed on valve body. Gravitational force v/s time graph is obtained directly i.e. the magnitude of gravitational force can be directly noted from the graph and it is in mm/s². Only the peak points in positive direction should be considered as the actual value of 'g' as other points are not essential or are generated due to noise.

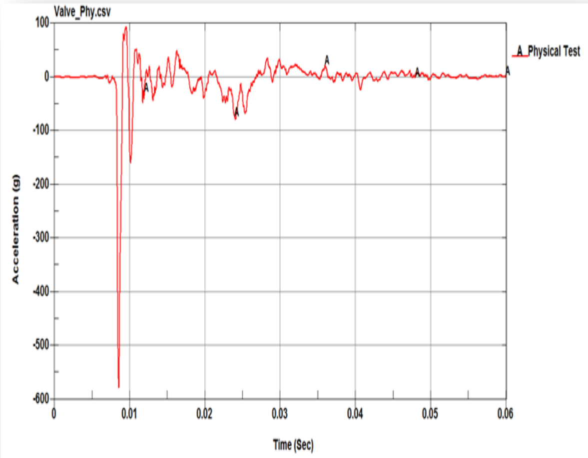

Fig -7: Gravitational force v/s time for valve body

4.2. Acceleration Result Data from Simulation

Similar to the experimental data obtained from accelerometer, we were able to find the gravitational force from simulation with the aid of LS PrePost. In this work we have obtained the gravitational (g) by using command ASCII in LS PrePost. Virtually acceleration points have been placed on lower tray and valve body which is similar to what is placed in the experimental setup and the initial velocity is given in particular direction. Following Fig-8 shows the acceleration points virtually placed on valve body along with the direction of motion during the simulation process.

Fig – 8: Virtual accelerometer on valve body

Following Fig-9 is the graph obtained from the simulation of the model for the rear incline impact scenario. The first peak values of these plots obtained is the required data. Unlike the experimental scenario, we do not get direct values of 'g'. Instead the values obtained have to be divided by 9810 which is the gravitational constant 'G' m/s². Contrary to experimental results, noises are not seen in simulation scenario.

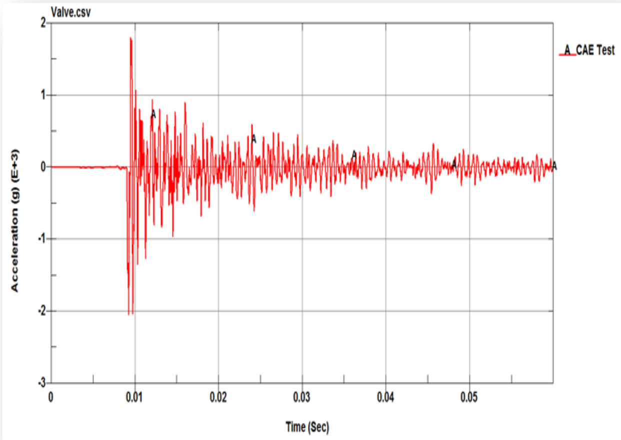

Fig -9: Gravitational force v/s time by simulation

5. COMPARISON OF SIMULATION WITH EXPERIMENTAL DATA

Comparing the acceleration data obtained from the experiment against those obtained from simulation, the similarity of the results is obvious. Following Table-2 compares the maximum gravitational force obtained from experimental and simulation data in X-direction.

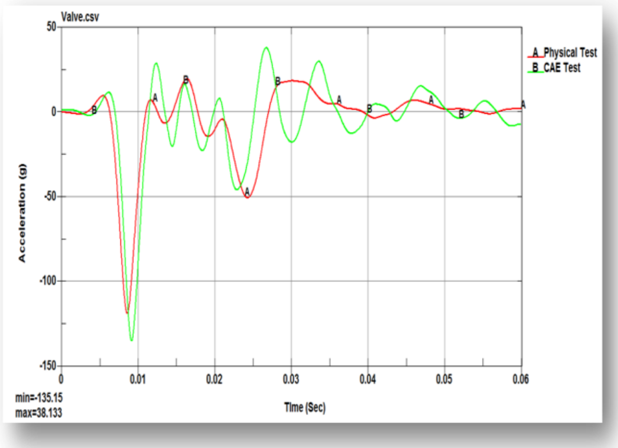

Fig -10: Gravitational force v/s time of Physical vs CAE Test Data

Table -2: Comparison of 'g'

Component	Experimental data (mm/s²)	Simulation data (mm/s²)	Error (%)
Valve body	124	130	4.6

6. CONCLUSIONS

Contour plots for rear components, shows that no major risk was seen and they are safe from the impact. The packaging element employed effectively absorbs the energy during the impact thereby ensuring the safety of the components as shown in Fig- 5. It is clear that the acceleration data obtained from both the simulation and experiment are in correlation with one another. Error of 4.6% is observed from the values obtained from experiment and simulation Also this implies that the simulation performed is a valid one and can be further utilized for other applications.

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