Drop Test Simulation and Verification of a Dishwasher Mechanical Structure

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ABSTRACT

It is critical for dishwasher manufacturers to design the front door hinge system and the structural components of a dishwasher assembly in terms of appearance and satisfying functional requirements. It is therefore necessary to know the maximum weight of decorative wooden door can be assembled to the built-in front door without endangering the durability on every single opening state.

ARÇELİK A.Ş. Dishwasher Plant R & D Structural Design Department decided to design a new door hinge with a new mechanical dishwasher structure to accomplish these requirements and to enhance more robust structure as compared to its current designs. Plastic bottom housing and the required new package module are the critical parts of this new mechanical structure. In this paper, the designs of these parts are analyzed in detail with a finite element model by accomplishing the drop test analyses.

The nonlinear explicit finite element code LS-DYNA® is used for the drop impact simulations. The main purpose of this study is to build a finite element analysis (FEA) model of the drop test of the free-standing dishwasher structure in order to determine the critical regions in the assembly. Drop test experiments are then conducted and the results are compared with the ones obtained from FEA. The FEA model can be used to provide any further improvements on the new structure and the packaging module of this new dishwasher platform.

Keywords: Dishwasher, mechanical structure, finite element modeling, packaging, drop test, drop simulation

1 INTRODUCTION

Dishwasher customers are highly sensitive to appearance of the front door. Therefore it is necessary to determine the weight of decorative wooden door can be assembled to the built-in front door. To meet such requirements, the door hinge system and the mechanical structure are re-designed on a new dishwasher model by ARÇELİK engineers.

Current mechanical structure consists of two side frames and two top traverse that are assembled to the stainless steel inner-tube with tox operations. The new structure consists of integrated stainless steel inner-tube (with a plastic bottom plate) that is assembled to plastic bottom housing. It also differs from the current design in terms of the distance between side frames to gain more robustness compared to the current mechanical structure. R&D Department decided to unify these two designs where a full stainless steel inner tube is assembled to a plastic bottom housing with increased frame distance. It is therefore necessary to analyze the plastic bottom housing and the required new package module to determine the critical regions in the assembly. Dishwasher R&D Test Department will also enhance its packaging test instructions by experiments and using the validated drop test FEA simulations.

Except military standards [1, 2] there is no free fall or impact test standards for home appliances. This might be due to the fact that the usage and the transportation of electronic devices vary in terms of the customers/end users and carriers. In such a case, manufacturers write their own standards or instructions according to their experience in design based on how these appliances are being transported to the users.

(a) Current Design (b) New Design

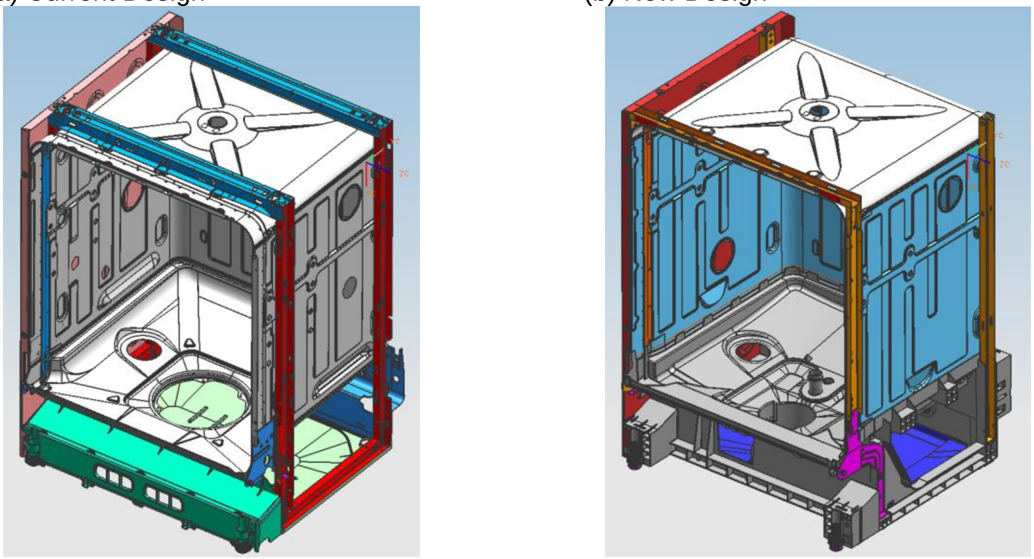

Fig.1: Configuration of the mechanical structure (a) Current design (b) New design

There are some studies on the experimental and finite element analysis of drop test simulation for mobile phones in order to investigate the stress and deformation analysis after impact to the ground [3-5]. Drop and impact simulations for the costumer goods (such as cooker [6] and television [7]) that also include the packaging module on the impact analysis also exist in the literature.

2 DROP TEST PLATFORM

In order to conduct experimental study, a drop test platform shown in Fig 2 is utilized. In this test the dishwasher can be dropped freely to one of the sides vertically (Fig. 2a) or with a pre-defined inclination angle (Fig. 2b) to its bottom plate. There is a rigid bottom plate and a mechanism which elevate the dishwasher to a desired height. After the height of the dishwasher is set, the mechanism starts to descend to its original position with a velocity higher than the dishwasher's impact velocity. Due to its higher velocity movement, dishwasher hangs in the air for an instance and then falls freely. Platform is also capable of inclined free fall tests to sides of the dishwasher bottom plate. This inclination is provided with a rigid side rod. In the inclined free fall tests, the dishwasher leans to this rod in order to provide the desired inclination.

(a) Vertical Drop Test (b) Inclined Drop Test to the Side

Fig.2: Experimental setup a) Vertical drop test b) Inclined drop test to the side

3 FINITE ELEMENT MODEL

The finite element analysis of this study is conducted using explicit nonlinear finite element code LS-DYNA. In the finite element model, the dishwasher is dropped from a predefined height with an initial velocity in order to decrease analysis time. The model consists of a packaging module and the mechanical structure of dishwasher. All parts are modelled in NX [8] and the finite element mesh is generated using HYPERMESH [9]. The overall dishwasher finite element model consists of 418,652 shell elements, 859,144 solid elements and 556 1D rigid and mass elements with a total number of 1,278,352 elements.

Considering the accuracy of the results and analysis time, the mesh size is chosen to be 8 mm for the parts where there is not much deformation and a minimum mesh size of 2 is used for the critical parts. Fully integrated shell element formulation is used for shell elements since it decreases analysis time compared to other formulations [10]. Fully integrated solid elements (S/R solid elements) are chosen to prevent excessive distortions that leads to negative jacobian errors [11].

Four different material types which are Type 20 **(*MAT_RIGID)**, Type 24 **(*MAT_PIECEWISE_LINEER_PLASTICITY)**, Type 63 **(*MAT_CRUSHABLE_FOAM)** and Type 124 **(*MAT_PLASTICITY_COMPRESSION_TENSION)** are used from the LS-DYNA material library in modeling the dishwasher assembly. *MAT 20 is defined for rigid wall. Type 24 which is an elasto-plastic material type, is used for steel parts of the dishwasher. Type 124 used for plastic components of dishwasher. This type is an elastic-plastic material where it is possible consider different tensile and compressive stress versus strain values. Type 63 material model is used for packaging module which is made from Expanded Polystyrene Foam (EPS). Because of the complex and highly varied behavior of foams, large number of material models are available in LS-DYNA material library. Based on the previous works [12, 13] Type 63 is found to be the best candidate for modeling EPS crushable foam. Poisson’s ratio of EPS crushable foam is taken to be zero (see for example the experimental work of Shah and Topa [12]). Since Poisson’s ratio is zero, volumetric strain in the stress versus volumetric strain curve is easily obtained from uniaxial strain. Tensile cutoff and viscous damping coefficient parameters are obtained from the study conducted by Ozturk and Anlas [14]. The parameters for the material model are listed in Table 1.

In order to validate the foam material model, a simple foam compression test (ball impact test) is conducted (see Fig. 3). Specimens of EPS crushable foam having square base with the side length of 80 mm and the height of 30 mm are compressed with rigid ball having 50 mm diameter as shown in Fig. 3. The finite element model of this test setup can be seen in Fig. 4. FEA simulation of this test is successfully performed in LS-DYNA. Taking advantage of the symmetry, a quarter model of the rigid ball and the foam block are analyzed as shown in Fig. 4.

Table 1: Some parameters of input card for Type 63

Parameter	Description	Value	Units
RO	Density	$2.2 \times (10)^{-11}$	Tonne/mm^3
E	Young’s Modulus	78	MPa
PR	Poisson’s ratio	0	
TSC	Tensile stress cut-off	0.1	MPa
DAMP	Rate sensitivity via damping coefficient	0.5	

Fig.3: Ball impact test machine

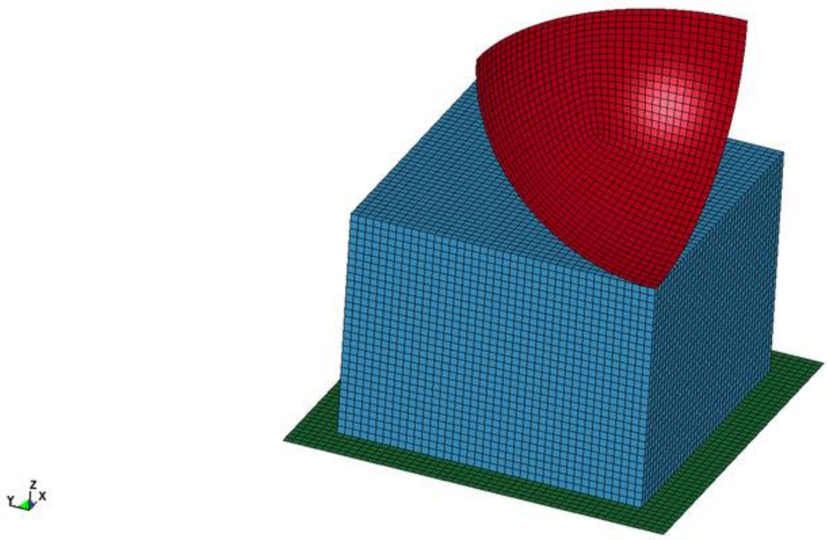

Fig.4: Finite Element model of the ball impact test

Ball impact simulation is successfully performed and the results are validated by the experimental work as shown in Fig. 5. These results prove that Type 63 material model with these parameters is successful in modeling the packaging module's material for the dishwasher.

***AUTOMATIC_SINGLE_SURFACE** contact card is defined between the parts of the dishwasher mechanical structure for the self-contact of each part. Contact between the rigid wall and the dishwasher is defined with ***AUTOMATIC_SURFACE_TO_SURFACE** contact card. Static and dynamic friction coefficients for the deformable parts are taken to be 0.3 and 0.2 respectively for each contact definitions. Contact between support foams and the bottom foam is defined with ***CONTACT_TIED_NODES_TO_SURFACE** card.

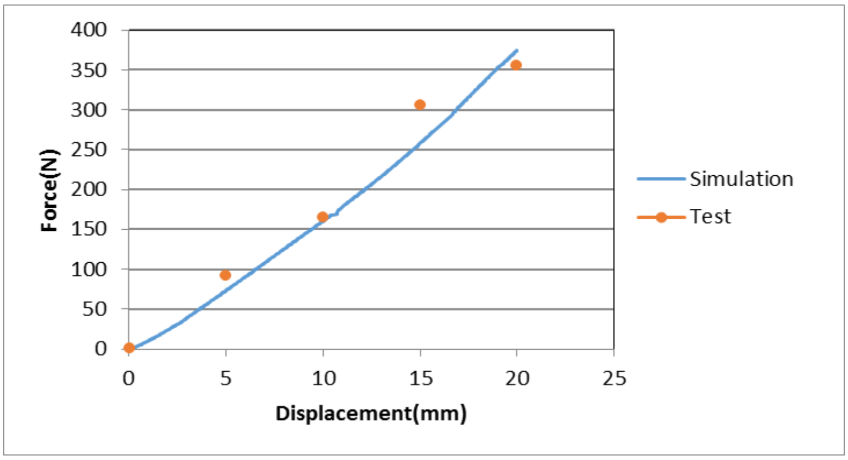

Fig.5: Comparison between the experimental and simulation results of ball impact test

Some components of dishwasher are modelled using mass elements. Nodes having mass points for these components are determined and masses of this components are defined on these nodes. Furthermore, **`*PART_INERTIA`** card is used for some components. This card requires calculation of the mass moment and center of mass of the respective components in order to provide inertial effects.

In order to minimize the simulation time, drop height of the dishwasher are decreased and the analysis is started at that point with an **`*INITIAL_VELOCITY_GENERATION`** card using Eq. (1):

$$V = \sqrt{2gh} \tag{1}$$

where *h* is the drop height of the dishwasher, *g* is the acceleration of gravity and *V* is the initial velocity of the dishwasher.

The finite element model of dishwasher assembly can be seen in Fig. 6.

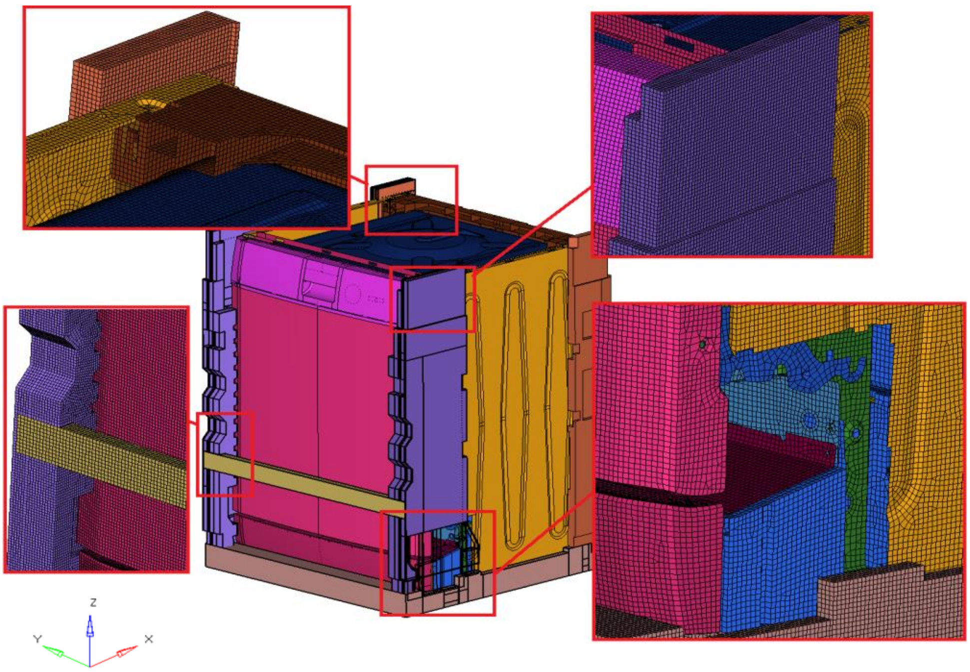

Fig.6: Finite element model of the dishwasher

4 RESULTS AND DISCUSSION

Drop tests of dishwashers are generally conducted with three different orientations such as inclined to front, inclined to side and vertical drop test in ARÇELİK group. In this study, inclined to side and vertical drop tests are realized and their finite element simulations are done. LS-DYNA models of these two cases can be seen in Fig. 7. Vertical drop test simulation is performed to determine the critical regions of the mechanical structure and the packaging module. It is seen that the critical regions include especially the components that come to contact with bottom foam. Then, inclined drop test simulation is performed and the critical parts are determined. As expected, parts at the inclined side of the dishwasher is the most affected parts in the dishwasher assembly during impact to the ground.

(a) Vertical drop test FEA model   (b) Inclined drop test FEA model

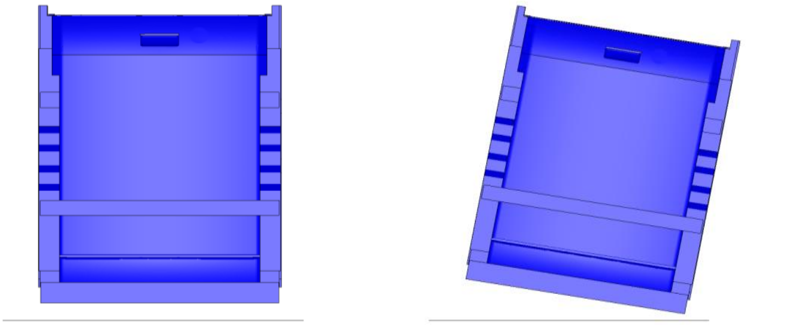

Fig.7: LS-DYNA models (a) Vertical drop test FEA model (b) Inclined drop test FEA model

It is observed that packaging module of the dishwasher absorbs most of the impact energy when the dishwasher impacts rigid ground. The deformed geometry of the bottom foam at the contact region is shown in Fig. 8a. In inclined drop test, the deformation at the bottom foam is much higher than the vertical drop test as illustrated in Fig. 8.

(a) Vertical drop test   (b) Inclined drop test

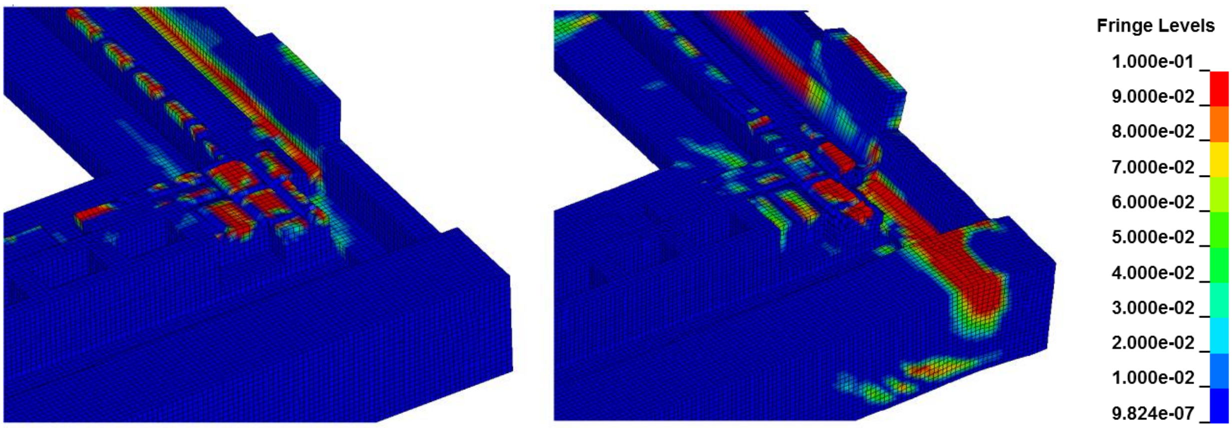

Fig.8: Contours of plastic strain at the bottom foam (a) vertical drop test (b) inclined drop test

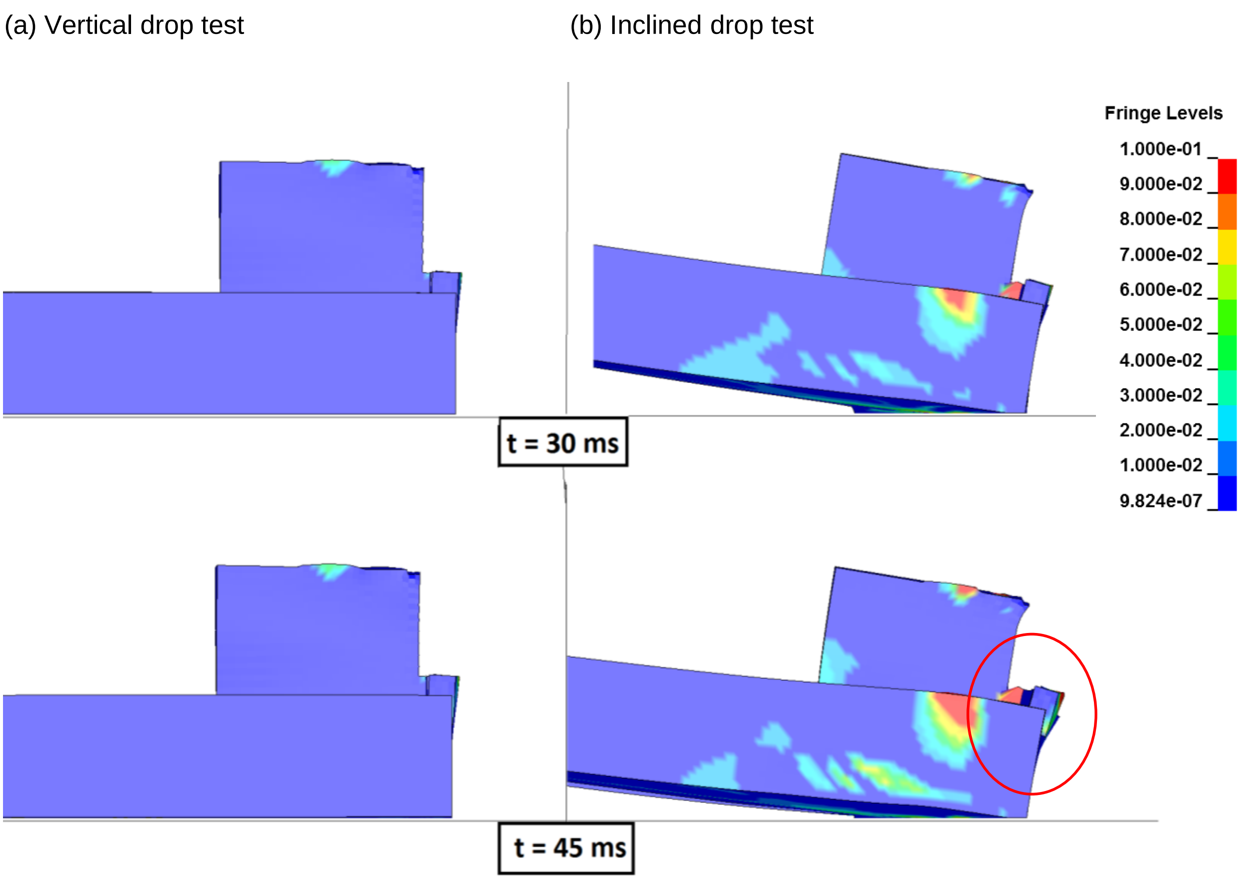

Fig.9: Contours of effective plastic strain at the bottom foam (a) vertical drop test (b) inclined drop test

The deformed geometry of the sidewall during contact with the ground at 30 ms can be seen in Fig. 9.

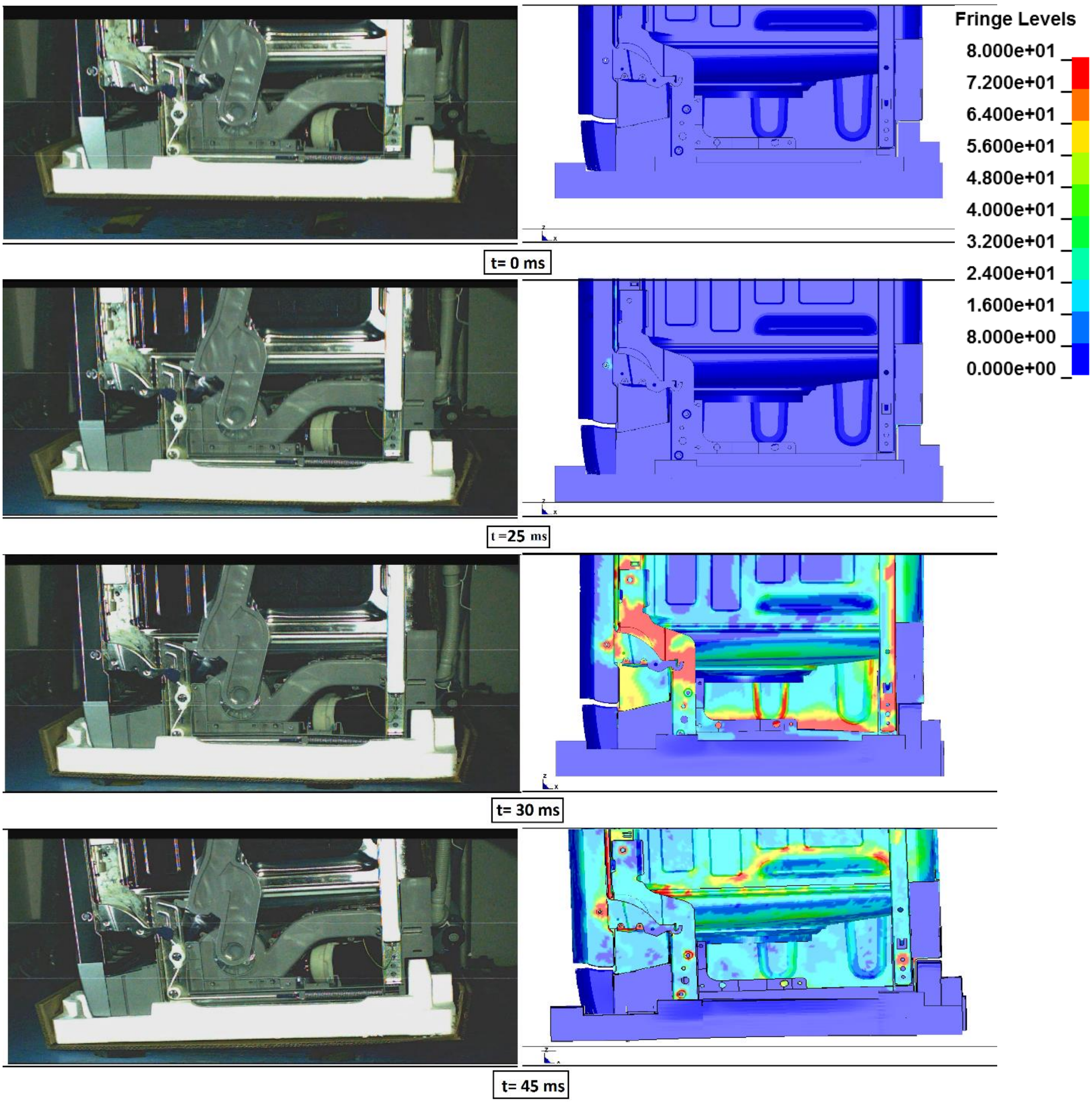

Fig.10: Comparison of vertical drop test with FEA results (effective stress contour in MPa)

Fig. 10 shows the comparison of the vertical drop tests with FEA results. The tests are recorded with high-speed camera and the deformations are compared with FEA simulation at certain time steps as shown in Fig. 10.

The deformed geometry of bottom foam after the vertical and inclined drop tests is shown in Fig. 11 and Fig. 12 respectively. As it is indicated in these figures, experimental and numerical results are well in agreement.

(a) Experimental results (b) Simulation result

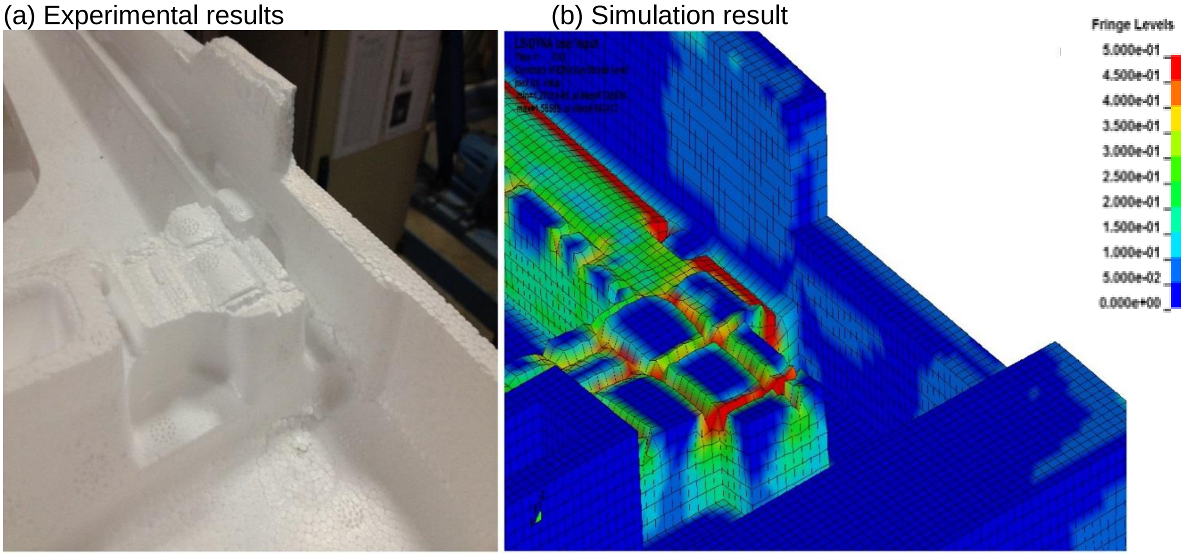

Fig.11: Comparison of the deformed geometry of the bottom foam after vertical drop test (a) Experimental result (b) Simulation result (effective stress contour in MPa)

(a) Experimental results (b) Simulation result

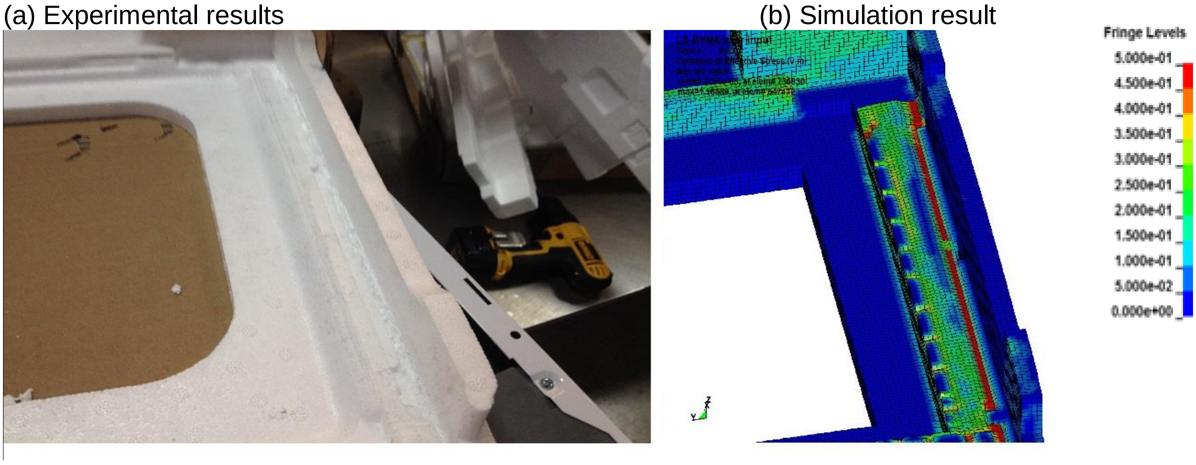

Fig.12: Comparison of the deformed geometry of the bottom foam after inclined drop test (a) Experimental result (b) Simulation result (effective stress contour in MPa)

5 CONCLUSIONS

In this paper, both experimental and finite element analysis of drop test are conducted in order to determine the critical regions of the new dishwasher assembly. Vertical and inclined drop tests are successfully simulated in LS-DYNA. The simulation results are compared with experimental drop test images. Plastic bottom housing and the new package module are found to be the critical parts of dishwasher. Results of simulation shows that plastic bottom house of the dishwasher is not affected much compared with packaging module. Therefore, in this paper packaging module is analyzed in detail and verification of the results are done by checking the deformation behavior of packaging module during impact. Deformation behavior of the bottom foam are similar for both FEA and experimental results. The FEA model will provide further improvements on the new structure and the packaging module of this new dishwasher platform. ARÇELIK A.Ş dishwasher plant will use this new mechanical structure to whole product range. The optimization of the packaging module will be made for future study.

6 ACKNOWLEDGEMENT

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