Creep study of expanded polystyrene used in Refrigerator packaging

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1 Abstract

The efficient staging and storing of home appliances in warehouses are critical to avoid human injuries and huge losses to the company. After manufacturing the packaged product needs to be stored for a particular duration in the warehouse before it’s shipped out to suppliers. For optimum space management, those products are stacked one over the other. So it is important to have a robust packaging design to ensure even distribution of stacked product loads maintains their stability.
Considering the constant loading over a longer period there is a high possibility of creep effects in packaging material, and it becomes even more crucial when packaging material is Expanded Polystyrene (EPS). So it's imperative to study material creep behavior in designing product packaging.
In this study creep behavior of EPS material is evaluated with standard test setup, where precise measurement is done to get creep curves. The results were obtained for long-term constant compressive loading at different stress levels for multiple material densities, at ambient temperature 23°C.
FEA methodology has been developed using LS-DYNA implicit code, *MAT_UNIFIED_CREEP material card is used to map creep behavior of EPS. This approach has further been used to evaluate product stack lean behavior. A good agreement was observed between the experimental and numerical investigations.
This simulation capability will help to reduce the significant amount of time and resources used for physical tests. Also, this early prediction of stacked product behavior helps to reduce safety hazards and occurrences in the warehouse.

Keywords: Refrigerator, Expanded Polystyrene, Home Appliance, Creep, Stack, LS-DYNA Implicit.

2 Introduction

Refrigerators are one of the most important household appliances, used to keep the food fresh and hygienic. Refrigerators manufacturing companies worldwide use to build up refrigerator products during the non-seasonal period and maintain a healthy inventory that can sell during high demand of the products. Inventory management and storing of the products in the warehouse are some of the major challenges encountered by many companies. Especially during the peak production periods, space availability to store the products is a challenge. Due to space storage issues, production may stop until the warehouse space is made available. If we place all the products on the floor, a huge area is needed to accumulate the high volume of products. To overcome this inventory and space management problem in the warehouse, manufacturing companies stack up the product one above the others to optimize the available floor area in the warehouse.

Fig. 1 shows the product stacking in a warehouse. The stacking of the product depends on the height of the warehouse, while in most cases the stacking of the product is majorly driven by the weight and dimension of the product.

Fig. 1 : Three products stacking in the warehouse.

The manufactured refrigerator products are packed up by using expanded polystyrene (EPS) and cartons or in some cases by shrinkwrap to keep the product damage free during the transportation. Expanded polystyrene plays a vital role in keeping the product safe by absorbing maximum impact energy when product is subjected to abuse loading during transportation. It was clearly understood that the density of the expanded polystyrene (EPS) also has a major effect on the choice of this material grade. If the density of this material is high, stiffness will be high and vice-versa, this plays a critical role during product stack load case. Along with material stiffness, another important aspect is creep. Since the products remain in stacked condition for a longer duration in the warehouse, they will be subjected to constant loading over a longer period of time.

Expanded polystyrene (EPS) is sensitive to time-dependent deformations which is known as creep. When a constant magnitude load is applied on the expanded polystyrene (EPS), deformation of the EPS increases concerning the time. Extensive research has been made to study the creep behavior of the EPS under different loading conditions, with extensive material testing. The study aims to perform testing on the EPS creep considering the 50 cubic millimeter test sample [1] subjected to compression loading. Depending on the applications, the different EPS densities are considered for this study. Creep constants evaluated from this physical test are further used in FEA analysis performed in LS-DYNA implicit code followed by correlation study of creep deformations.

3 Methodology

Fig. 2 shows the creep constant evaluation: flow chart. Different actions and development plans were illustrated clearly in the flow chart. Initially, a sample of 50 cubic millimeters is considered for compression tests under various loading to get appropriate stress levels. Creep test data (time vs. deformations) is extracted by using various digital equipment to measure the deflections of the EPS cube with respect to time. This test data was converted into a relevant engineering term time (sec) vs. total strain. Most of the finite element analysis software requires creep constants as a material input to evaluate the deformations and other mechanical parameters. To generate this material creep constant a creep calculator is developed with help of a modified time hardening [3] method as shown in the equations below. Where the effective creep strain, ε_{cr} , given as

$$\varepsilon_{cr} = A_0 \sigma^m t^n \qquad \text{Eq (1)}$$

Where A_0, n, and m are constants and t is the effective time. The effective stress, σ considered as per loading. The calculator-generated creep constant values are given as the initial inputs into the LS-Dyna software as material constants. This creep material constant helps to develop the mathematical curve and it should resemble the actual testing curve. Fine-tuning of the creeping material constant is required if the mathematical curve deviates from the actual testing curve. Once a reasonable mathematical curve is obtained,we can use this refined creep material constant in finite element analysis software. In this study, we are evaluating the creep constant from the inbuilt calculator and then re-evaluate it in the LS-Dyna software with therefined creep constant used as the initial material constant for further analysis.

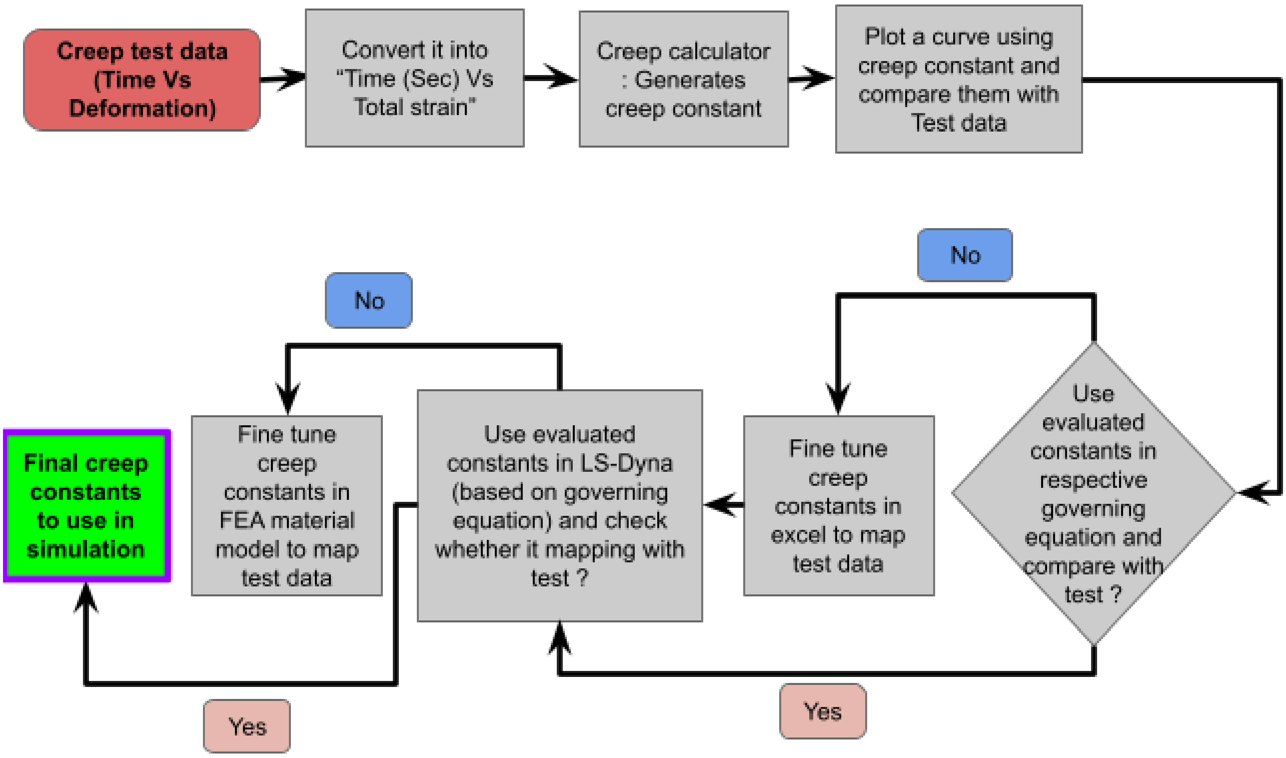

Fig. 2 : Creep Constant evaluation: Flow Chart

4 FE modeling

In this study, a sample of 50 cubic millimeters under the compression load is modeled and studied. For the experiment purpose, 2 pound per cubic feet (PCF) and 3.5 PCF density of expanded polystyrene (EPS) were used. Fig. 3 shows the FEA model of the cube.

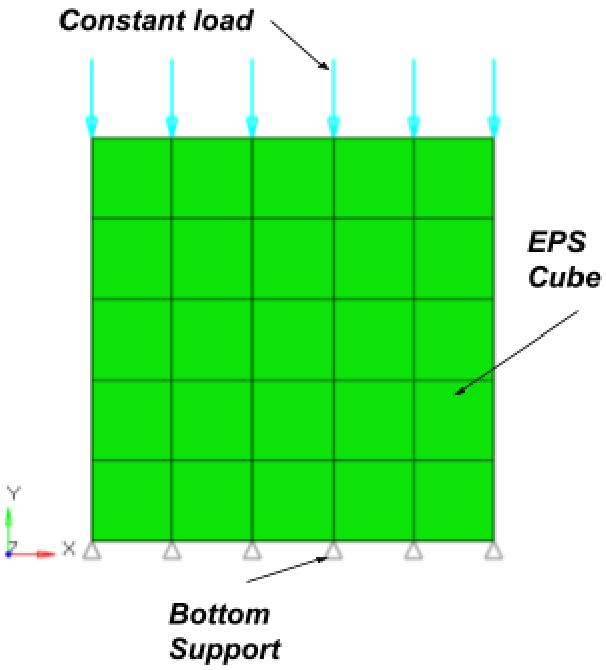

Fig. 3: The FEA model of the cube

To study the creep effect of the material on the cube, the FE model is built using pre-processing software. This cube is supported from the bottom side. The constant load applied on the top face of the cube to generate expected stress levels. A pre-calculated element size of 10 mm was considered for the cube to obtain the block mesh and ELFORM = -2 was considered. Lower element size has been intentionally avoided that may cause the computational failure in elements due to the over-compression.

Material model *MAT_UNIFIED_CREEP (TYPE 115) [3] used to predict creep behavior of the EPS, where deformations in the cube with respect to time under the compression loading are evaluated. Creep constant evaluation from the test data and the curve fitting method is considered as the material inputs.

5 Experimental work

Creep testing is performed for EPS material samples of 2 PCF and 3.5 PCF densities as per the standard creep test procedure. This testing is performed at multiple stress levels for respective densities.

6 Correlation study

Initially, a strong methodology developed for creep strain material mapping on EPS samples as aformated above. This study has helped to evaluate creep material constants required as an input for material definition in LS-dyna. The strong agreement between test vs simulation results of material mapping has helped to predict the actual product stack behavior through LS- Dyna implicit code.

Depending on application, the physical test on 50 mm3 cube samples of 2 & 3.5 PCF EPS density has been performed for different stress levels. strong agreement has been established between physical tests, FEA outcomes and curve fitting. The correlation for 2 PCF EPS density can be seen from fig. 5 and correlation for 3.5 PCF EPS density can be seen from fig. 6.

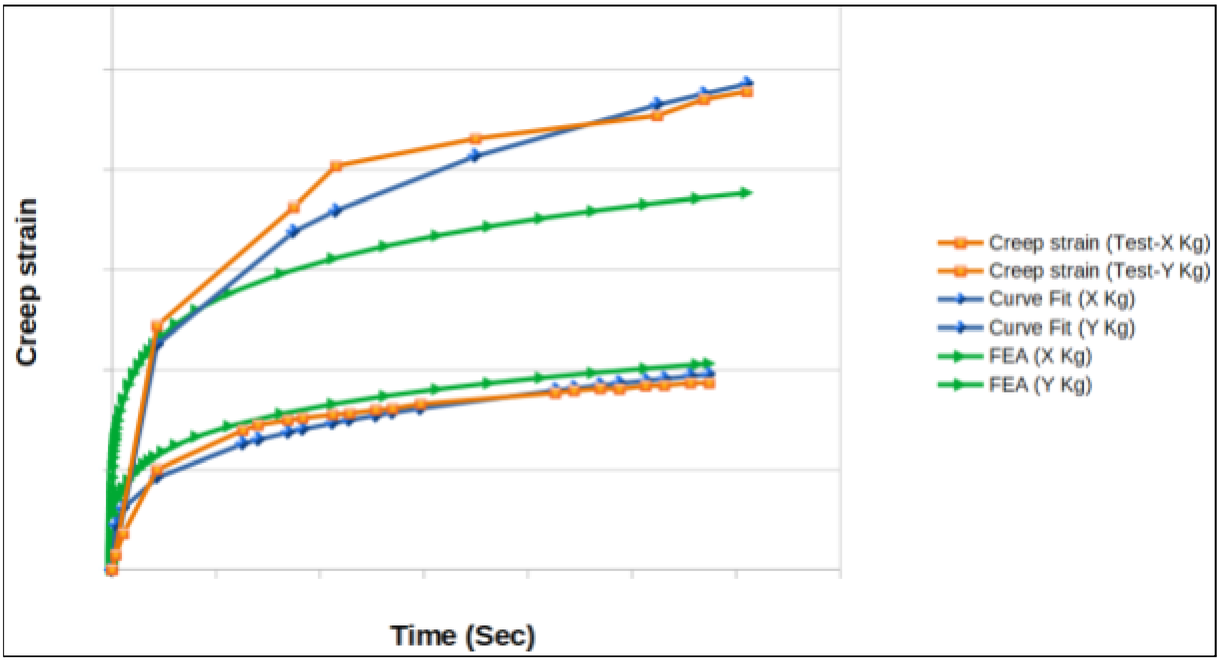

Fig. 5 : FEA Vs Test creep curve for 2 PCF

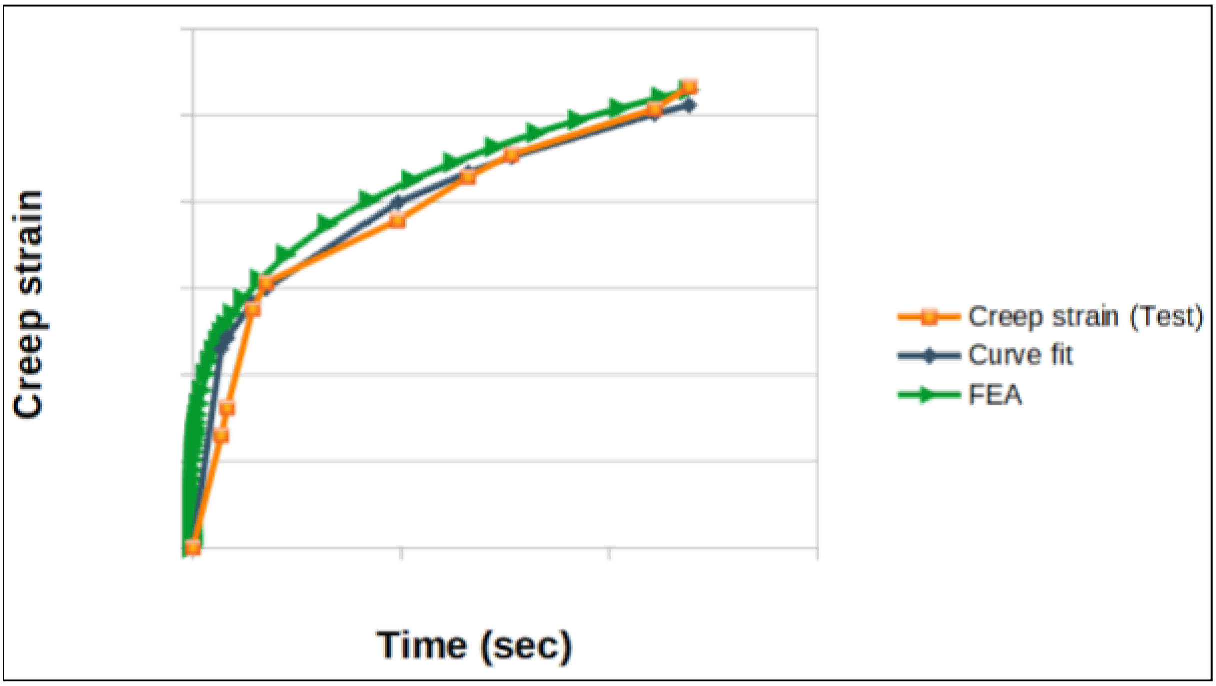

Fig. 6 : FEA Vs Test creep curve for 3.5 PCF

The material constants evaluated from the afformated correlation study and used in the FE modelling of product stacked columns. This stack loading simulation performed for 30 days to study the effect of creep on product stack lean. The products from different architectures of refrigerators are selected and evaluated using LS-DYNA implicit code [2].

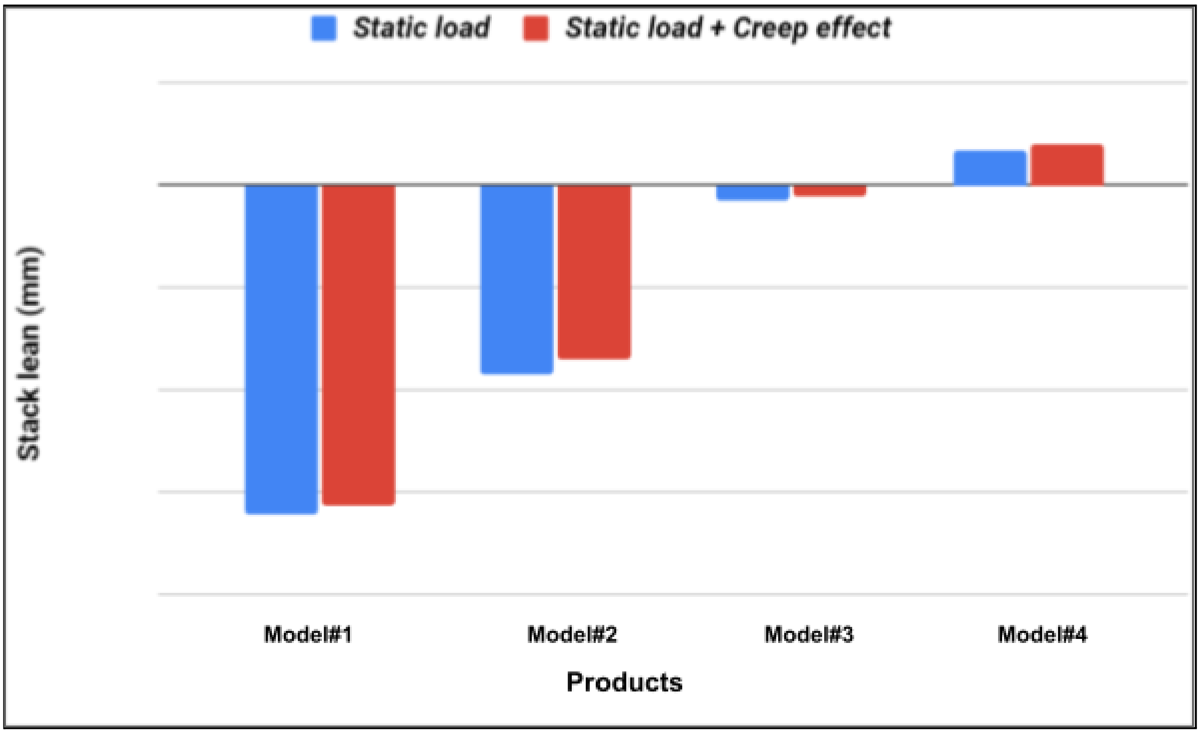

Fig. 7 : Stack lean correlation

Fig. 7 shows stack lean correlation with addition of creep effect, for multiple product configurations. It has been observed that marginal impact is observed with incorporation of creep effect at room temperature on overall product stack behavior. The further study has been planned with elevated temperature conditions to predict the stacklean behavior at higher temperature conditions.

7 Summary and Conclusions

The FE analysis in LS-DYNA implicit code using *MAT__UNIFIED_CREEP material model shows a strong agreement with the physical creep material test data. This mapping has shown a good trend in both primary and secondary creep stages for EPS.

This material study has helped to understand the most critical parameters influencing product stack lean behavior. The variation study of critical parameters is further planned for this study.

Application of creep material model to multi product stack lean model at room temperature shows marginal improvement in lean values. Further investigations are planned to study the effect of creep at elevated temperatures.

8 References

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