Stacking strength of expanded polystyrene boxes with fish storage capacity between 3 and 25 kg

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Introduction

Expanded polystyrene (EPS) boxes with volume capacity of 6 – 50 L are commonly used to transport fresh fish products via air and sea. Those volume capacities correspond to around 3–25 kg of fillets/whole fish. EPS boxes are normally white, made from molded polystyrene beads and composed of around 98% air (www.eumeps.org/).

Insulation capabilities of the packaging is a very important property to maximize the quality and safety of the perishable fresh fish (Margeirsson, 2012). Failures within the cold chain lead to losses of around 20% in the world food supply and 9% in developed countries (IIR, 2015).

The other main important physical property of fresh fish packaging is structural strength. Handling of EPS boxes filled with fresh fish products can be very rough as can sometimes be experienced by observant airline passengers (see Figure 1).

Tempra in Hafnarfjörður is the largest manufacturer of EPS boxes in Iceland. Helgason (2018) studied the strength of Tempra's 23-kg EPS boxes under three different load cases, both with computational modelling and experiments. His results show that an EPS box with volume capacity of around 40 L and designed for around 23 kg of fish can be expected to withstand around 8-9 kN load (equivalent to around 815–917 kg weight) when inclined at an angle of 15 degrees. The lower numbers refer to boxes equipped with drain holes and the higher numbers to boxes without holes.

Figure 1. EPS box being thrown from around 1 to 1.5 m height on a conveyor belt during loading into a passenger airplane.

The aim of this study is to compare the compressive strength of different EPS box types manufactured by Tempra, i.e. boxes designed for 3–15 kg of fillets and 23–25 kg of whole fish. The comparison includes a new 23-kg box type, which Tempra started manufacturing in May 2019.

Materials and Methods

The strength of the boxes was evaluated by measuring the force versus displacement until the boxes failed (Figure 1). The equipment used was a 200/100-kN static/dynamic load cell, hydraulic press and controller from Instron in addition to WaveMatrix software, also from Instron. One load case was implemented, i.e. uniformly distributed load on horizontal box with the lid on (Figure 2 and 3). For more information on the equipment, refer to Helgason (2018).

Figure 1. Broken 3-kg box (left) and lid (right) after having been loaded with around 510 kg weight on top of the box with lid on.

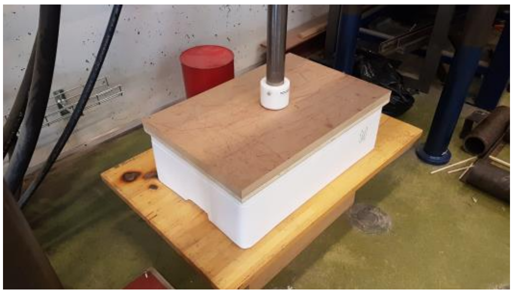

Figure 2. 15-kg box under uniformly distributed vertical top load.

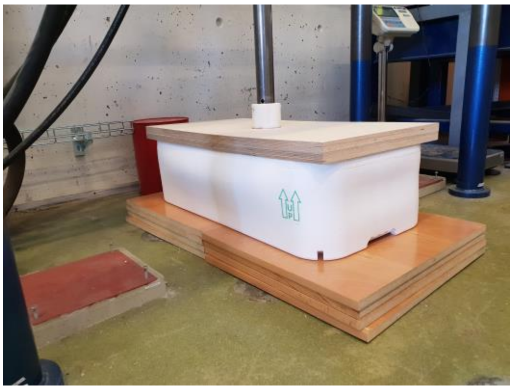

Figure 3. New 23-kg box with drain holes under uniformly distributed vertical top load.

The box types along with the most important physical properties are shown in Table 1. Five boxes were tested in each experimental group. The tested boxes had density of around 23 kg/m^3.

Table 1. Experimental groups.

Box type	Volume capacity (L)	External height (mm)	No. of drain holes	Weight (g)
3-kg fillet box	6.1	126	0	180
5-kg fillet box	8.0	149	0	199
5-kg long fillet box	7.2	135	0	218
7-kg long fillet box	9.8	164	0	242
10-kg fillet box	16.1	142	0	416
13-kg fillet box	19.6	161	0	437
15-kg fillet box	21.1	173	0	447
23-kg fish box (old)	40.2	230	0	703
23-kg fish box (new)	41.0	225	0	669
23-kg fish box (new)	41.0	225	4	667
25-kg fish box	48.5	264	0	730

Results and Discussion

The average maximum loads during the top-load trials are presented in Figures 4-6. The maximum loads obtained for the smaller fillet boxes (3–7 kg) range from around 5.04 to 6.00 kN, equivalent to around 510 to 610 kg. These values can be compared to the maximum weight in real situations when transporting fresh fish fillets. In case of the 3-kg box, its height is 126 mm and due to height limitations in refrigerated sea containers, no more than 17 box layers are stacked on a pallet, resulting in a stack height of 2.14 m. A stack of 16 boxes, each containing 3 kg of fish +2% overweight + 0.18 kg box weight, results in around 52 kg weight on top of each bottom box on the pallet. A safety factor of almost 10 (510 kg/52 kg) should in almost all circumstances account for the difference between the controlled, slowly applied (0.25 mm/s) load in the current tests and variable, dynamic loads applied during real transport of fish.

Using the same method for the 5-kg, 5-kg long and 7-kg long boxes, safety factors of 7.5, 8.2 and 6.4, respectively, are obtained.

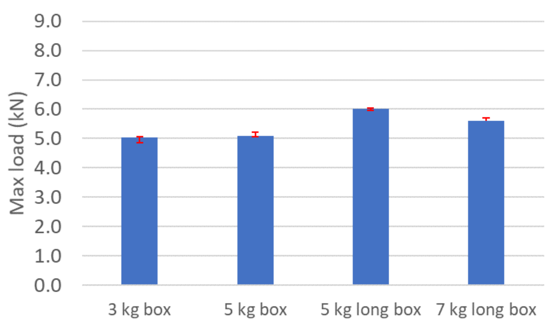

Figure 4. Average maximum load during vertical top load test on 3–7 kg box types. The number of boxes tested in each case was 5 and the error bars indicate standard deviation.

According to the results of the current study, the 10–15 kg boxes can withstand up to around 7.5 to 8.0 kN load, corresponding to around 760 to 820 kg (Figure 5).

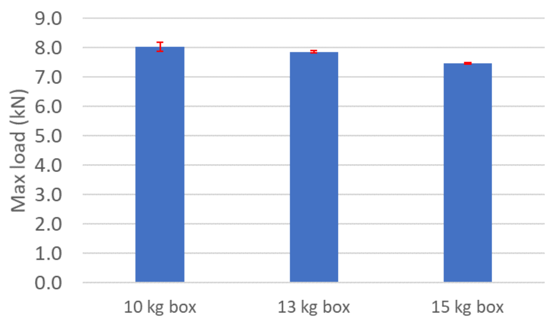

Figure 5. Average maximum load during vertical top load test on 10-, 13- and 15-kg box types. The number of boxes tested in each case was 5 and the error bars indicate standard deviation.

The external height of the 15-kg box is 173 mm. The height of a pallet stack of 12 levels is therefore 2.08 m and again assuming 2% excess fish weight, the weight on top of the bottom box on the pallet is then around 173 kg (safety factor of around 4.4 compared to the 760 kg obtained in the current study).

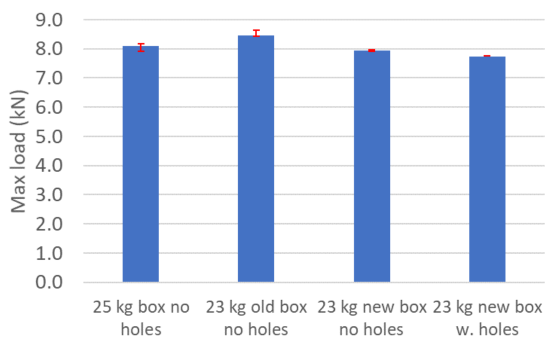

Figure 6. Average maximum load during vertical top load test on different 23- and 25-kg box types. The number of boxes tested in each case was 5 and the error bars indicate standard deviation.

The stacking strength of the largest box types, i.e. the 23- and 25-kg boxes, is presented in Figure 6. The average strength proved to be highest for the old 23 kg box without drain holes (8.46 kN or 862 kg), which is still interestingly 5.7%

lower than Helgason (2018) measured using a 15 ° sloped load. The calculated safety factor for the old 23-kg box was 4.5.

The new 23-kg box without holes proved to be 6.1% weaker than the old 23-kg box (7.95 kN/810 kg vs. 8.46 kN/862 kg). The new box is around 5% lighter than the old box, which should decrease transport costs and environmental impact of the packaging.

Table 2: Maximum uniformly distributed weight on top of the new 23-kg box ± standard deviation.

	With drain holes	Without drain holes
Max. weight (kg)	787 ± 3	810 ± 3

The drain holes decrease the stacking strength of the new 23-kg box under top load by 2.8% as compared to the same box with drain holes, see Table 2. However, stacking 9 levels of the 23-kg boxes reaching up to 2.03 m height, results in only around 189 kg load on each bottom box on the pallet. Comparing this number to the 787 kg, obtained in the current study, results in a safety factor of around 4.2.

The average maximum load on the 25-kg box without drain holes was 8.09 kN, equivalent to 824 kg. Stacking these boxes 8 levels up results in stack height of 2.11 m and around 180 kg load on top of each bottom box on the pallet. This implies a safety factor of 4.6 (824/180).

Conclusions

The expanded polystyrene boxes studied, ranging from 3 to 25 kg in fish storage capacity, proved to withstand uniformly distributed load ranging from 510 to 862 kg. The smallest boxes had the lowest stacking strength, but by considering how the boxes are usually stacked on pallets, the smallest boxes are probably the most unlikely to fail. This can be seen by comparing the relatively high safety factors calculated for the smaller boxes (6.4 to 9.9) to the ones for the larger boxes (4.2 to 4.6).

Future work could include measurements applying load types different from the one in the current study. This could give interesting information on the bending strength of walls and bottom of the boxes. Furthermore, comparison with packaging materials other than expanded polystyrene might be valuable for the stakeholders in fresh fish transport chains.

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