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Simulation Technique for Transport Test of Fruits and Vegetables

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Introduction

Various kinds of packing materials for fruits and vegetables are used to prevent in-transit mechanical damage received from shock and vibration during long distance transport. However, some packing systems currently used lack the capability for preventing damage of the products, or in contrast, some ones overprotect the products. Methods for designing a suitable packing system were not yet develped because of a lack of information about physicomechanical properties of the products as well as the present status of transporting condition.

In order to overcome a part of the problem, the simulation technique for transport test of fruits and vegetables has been developed which could simulate an actual transport condition in a laboratory.

Theory of the transport simulation technique[1)]

In-transit mechnical damage of fruits and vegetables was assumed to be fatigue failure due to an accumulation of damage caused by vibrating acceleration which acted on the products during transport. The Palmgren and Miner's hypothetical law, which is useful for the fatigue analysis of metallic materials, was applied to estimate the degree of the damage.

As shown in Fig. 1, S-N curve represent the relationship between the amplitude of stress(S) and number of repetitions (N) which is permitted to the extent where the products come up to a fatigue failure point. In the field of metallic material, the relationship between S and N is obtained empirically as follows[2)].

$$N \cdot S^{\alpha} = \beta \quad \cdots\cdots (1)$$

where α and β are constants which depend on the material. In case of the problems of transport, the stress subjected to the products can be thought to correspond to the vibrating acceleration (G) during transport. Therefore equation (1) can be written as follows :

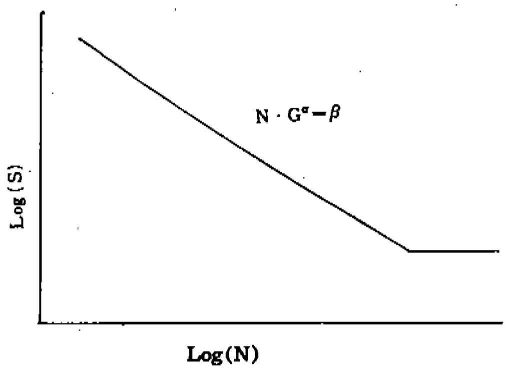

Fig. 1. S. N Curve(Wohler curve)

$$N \cdot G^{\alpha} = \beta \quad \cdots\cdots (2)$$

When the products meet the vibrating acceleration (G) occurring in the number of repetitions (n), the degree of damage (D) can be evaluated from Palmgren and Miner's hypothetical law as follows :

$$D = n/N \quad \cdots\cdots (3)$$

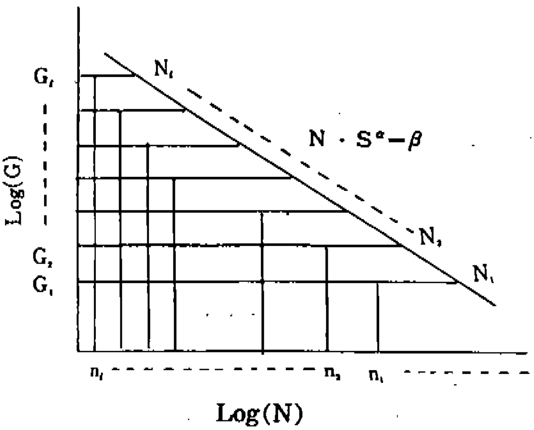

Fig 2. Evaluation method of the degree of damage by means of S-N curve

If the products meet various magnitude of vibrating acceleration (G_i) occurring in the number of repetitions (n_i) respectively as shown in Fig. 2. the totalized degree of damage is determined from

$$D = \sum' (n_i/N_i) \cdots\cdots\cdots\cdots \quad (4)$$

When D reaches 1, it can be seen that the products lost their marketability completely. From equations (2) and (4), the following equation can be easily derived.

$$D = \frac{1}{\beta}\sum n_i - G_i^{\alpha} \quad \cdots\cdots\cdots\cdots \quad (5)$$

that is, if the constants of α and β and the number of repetitions at every magnitude of vibrating acceleration on the recorder chart of accelerometer are known, the degree of damage during transport can be determined form equation (5).

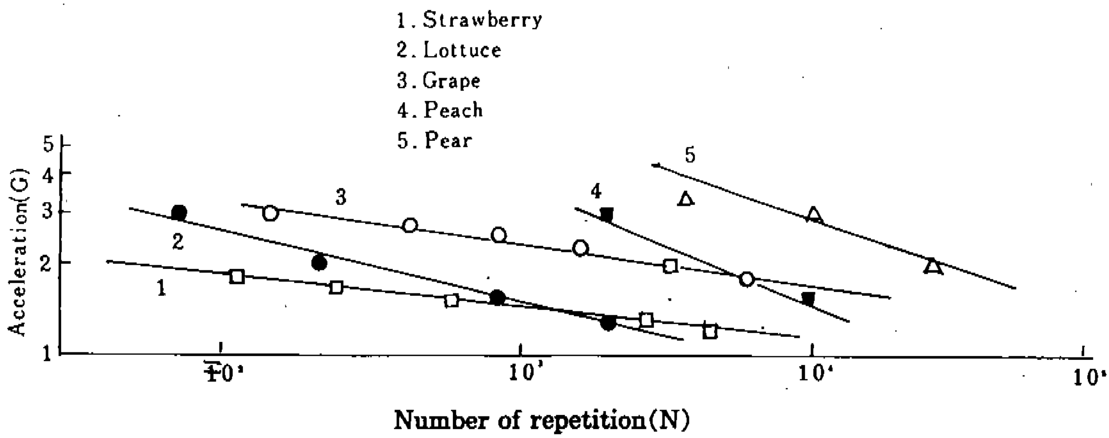

Fig 3. S-N curve of different produces

Fig.3 showns S-N curves which were obtained from simulated vibration tests with strawberries, lettuces, peaches, grapes and pears packed in several types of carton-box as summarized in Table 1. A laboratory vibrator of 2000 kgf capacity was used for the test. The vibrator could yield a constant amplitude of acceleration in the frequency range from 5 to 50 Hz. The direction of vibration was up to down and a carton-box with the products was fixed on the vibrator table. The frequency range used for vibrating test was from 5 to 10 Hz driven by sweeping method for strawberry and 7 Hz for others. Sweeping time was 200 second. The frequency of 7 Hz is close to a resonant frequency of the carton-box at the top layer among six or seven highly stacked carton-boxed on the truck bed.

Through the test, the products were individually scored on a scale from 1(unbruised) to 5 ()completely bruised. When the score above 3 was given to a product, the marketablilty of the product was lost.

It is important to estimate the amplitude of vibrating acceleration for simulated transport test in a laboratory. Simulated transport test needs to cause a simuilar degree of damage in case of the actual transport. For this purpose, a convenient solution was derived from S-N curve and equation (5) as follows :

The occurring times of vibrating acceleration during

Table 1. Filling method of produces or packaging material and the constants of α and β for S-N curve

Produces	Filling method or packaging material	α	β
Strawberry	Filled in bulk into a PVC tray of 300g capacity. Capacity per carton-box is 1.2kg.	9.26	2.65×10^4
Lettuce	Filled in bulk into a carton-box of 10kg capacity.	4.17	5.32×10^3
Grape	Filled in bulk into a carton-box of 4kg capacity.	6.99	4.13×10^5
Peach	Filled in PVC pack. Capacity per carton-box is 5kg.	2.44	2.46×10^4
Pear	Filled in PSP pack. Capacity per caton-box is 15kg.	3.00	2.27×10^5

the actual transport being known with respect to every amplitude of acceleration, it is possible to evaluate the degree of damage by equation (5). If a sinusoidal vibration is used to vibrate the products for the times of $\sum n_i$, the amplitude of equivalent vibrating acceleration ($\overline{G}$) which causes a similar degree of damage in the simulated transport test is given as follwos:

$$\overline{G} = \left(\frac{\sum n_i \cdot G_i^{\alpha}}{\sum n_i}\right)^{\frac{1}{\alpha}} \quad \cdots\cdots (6)$$

Evaluation of in-transit damage

Table 2 summarizes the degree of damage of several fruits and vegetables during transport. The statistical data concerning the occurring times of vibration acceration with respect to it's every amplitude were quoted from other papers including our work as shown in the table. In all the papers, portable accelerometers of the same type were tightly fixed in the carton boxes. It can be seen from Table 2 how the condition of the products after transport is and whether the package should be improved or not. For example, the degree of damage of pears was almost zero, so it was concluded that there was some room to change the packing material for package to a simple one. On the other hand, in case of strawberries, the marketability was easily lost even through the distance of transport was less than a 150 km.

Table 2. Degree of in-transit mechanical damage and equivalent acceleration of simulated transport test for different produces

Produces	Position of load	$\sum n_i$	D	G	Transport facility and transport distance	Ref
Pear	Top layer	419	0.004	1.26	Rail car with slipsheet, 820km	[1]
	Bottom layer	14	0	1.39		
	Top layer	52	0	1.30		
	Bottom layer	20	0	1.35		
Strawberry	Top layer of rear side	752	32.9	2.32	Refrigerated turck,684km	[2]
	Top layer of front side	167	0.23	1.55		
	Bottom layer of front side	17	8.44	2.79	Truck, 153km	[3]
	Bottom layer of rear side	531	55.8	2.36		
	Top layer of rear side	1,046	83.2	2.29		
Lettuce	Top layer of central part	11	0.005	1.25	Truck, 160km	[4]
	Middle layer of central part	2	0	1.25		
	Top layer of central part	221	0.429	1.75	Truck, 180km	
	Bottom layer of central part	38	0.084	1.80		
Grape	Top layer of rear side	1,121	0.333	1.99	Truck, 745km	[5]
	Top layer of central part	8	0.017	2.64		
	Top layer of rear side	1,461	0.609	2.09	Truck, 768km	
	Top layer of central part	69	0.147	2.64		

* [1] S. Maeya : Tetsudogikensokuhou, No. 71-132(1971) [2] Y. Chuma. J. Soc. Agr. Machinery, 31(4), (1970) [3] G. Hazu : Bulletin of Shizuoka Pref. Exp Sta., No. 9(1964) [4] M. Iwamoto : Unpublished [5] R. Nakamura : Bulletin of Fac. of Agr. of Okayama Unive. No. 47(1976)

Acceleration for simulated transport test

When the simulated transport test is made with grapes for example whose degree of damage is 0.333 as shown in Table 2, the condition of simulation are decided that the equivalent vibrating acceleration is 1.99 G and the number of repetitions of vibration is 1121 respectively. In case that a sinusoidal vibration of 7Hz is used for the simultion test, the treatment time of simulation is a approximately 160 second.

In this way, the conception of the degree of damage gives some suggestions how to evaluate the present conditions of commercial transport for fruits and vegetables. The accuracy of this evaluation for the degree of damage, however, entirely depend on S-N curve which represents the property of durability of products to transporting vibration.

Vibrating charateristics for multi-stacked corrugated fiberboard boxes

Multi-staoked corrugated fiberboard boxed were assumed to be a linear combination of the Voigt rheological model which has the equivalent vibrating characteristic of an individual corrugated fiberboard box. Vibrating response as a result of solving problems of a multi-degree-freedom-system of vibration was analyzed by means of a transfer matrix method. The vibrating responses of resonance frequency and transmissibility showed a fairly good agreement with those of the experiment.

In-transit mechanical damage of fruits and vegetables, and improvement of the packing systems currently used

1. Vibrating characteristics of lettuce packed in corrugated fibreboard boxes stacked in seven layers were examined together with a mechanism of in-transit mechanical damages. Resonance frequency of the box at the top layer was approximately 8 Hz for a non-banded stack and approximately 13 Hz for a banded stack. The mechanical damage was caused by a free rotation of the product in the box, particularly when excited by the resonance frequency. We found that the damage could be reduced by packing the lettuce in the box with the butt downward in oreder to aboid free rotation.

2. To improve the transport techniques of processing tomatoes, vibration characteristics of small type plastic containers were analyzed. In a five-high stack arrangement of containers filled with tomatoes, the ordinary condition for shipment, the vibrating acceleration at the top container was largest; the acceleration transmissibility at resonance frequency reaches approximately 4.0. As vibration time increased, softening of the flesh initated, followed by breakage of the products.

3. The efficiency of the packing system used for Japanese pear 'Nijisseiki' was evaluated using the simulated transport test. The packing system for the product was found more than necessary to protect the fruit from shock and vibration during long distance transport. We suggested that the packing system should be replaced by a simpler one.

Mechanical durability of liquid-type food containers against shocks and vibrations during long distance transport

A simulated transport test was applied to verify the mechanical durability of containers for liquid-type food.

1. Rectangular paperboard container

A simulated transport test was conduted using rectangular paperboard containers for fruit juice. The container at the top layer in the stack had resonance frequency of 9-15 Hz and maximum transmissibility of 4 to 6, depending on the kind of containers tested. There was a general tendency that vibration practice weakened seal strength of the container. Results of the simulated transport tests were compared those of actual transport tests carried out for a distance as long as

2000 km by trackhauling. It was found that the containers had safety factor large enough to withstand vibrations during an actual long distance transport.

2. Gabletop-type of aseptic paperboard-container

The durability of gabletop-type of aseptic of aseptic paperboard-container against shocks and bibrations during a long distance transport was evaluated. The degree of damage to the container subjected to vibration in a actual transport for 2,270km was evaluated on the basis of the number of accelerations recorded on a portable mechanical accelerometer. Judging from the fact the value was 0.11 at most, the container was thought to have enough strength to withstand vibrations during the actual long distance transport.

3. Bag-in-drum type of aseptic container

The durability of bag-in -drum type of aseptic container was examined when transported for more than 1200km; this type of container is becoming popular at present for orange juice or tomato puree. The container received many cracks and pin-holes. The damage was more serious in case of shipment by train than by truck and ferry boat because resonance frequency of the products in the aseptic bag was mostly equivalent to the lowest vibrating frequency of transporting vibration in the train. The damage could be reduced by suppressing the aseptic bag in the drum with two semicircular plates of polystyrene form.

Conclusion

In-transit mechanical damage of fruits and vegetables was thought to be a fatigue failure due to the accumulation of damage caused by vibrating acceleration during transport. A simulated transport test which cause a similar degree of damage in case of the actual transport was useful for designing a suitable packing system.

References

1. Iwamoto M., Kawano S. and Hayakawa A.(1978) Journal of the Society of Agriculatural Machinery, Japan, 40(1), 61～67.
2. Crandall S. H. and Mark W. D.(1963) Randam vibration in Mechanical Systems. Academic Press Inc.