ANALYSIS OF THE MECHANICAL BEHAVIOR IN THE USEFUL LIFE OF A CARDBOARD EXHIBITOR FOR POINTS OF SALE

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ANÁLISIS DEL COMPORTAMIENTO MECÁNICO EN LA VIDA ÚTIL DE UN EXHIBIDOR DE CARTÓN PARA PUNTOS DE VENTA

ABSTRACT:

This research work presents the study of the useful life of a cardboard Point of Purchase commercially known as POP. The proposed POP, is used as a tool of marketing to distribute, store and sell 700 tetrapack ™ packages of one liter per unit. The Integral Model of New Products (IMDNP) in its Phase II was used in this study to create a prototype and includes industrial design, failure analysis, Finite Element Analysis (FEM) and experimental evaluation with electrical Extensometry measurements. It considers also the redesign and modifications of the manufacturing process. In the experiment, the prototype was subjected to a maximum load during 3500 hours in order to identify its mechanical behavior. The importance of this evaluation can be seen in the case when a POP is not in good physical condition, the marketing process is interrupted even before the presence of mechanical failures. Its useful life is then reduced because the visual effect does not stimulate the intention of purchase of the customer. An improvement of 25% was obtained as a result of the application of the IMDNP in comparison with other traditional designs presented in this study, no visual deformations were observed before 2500 hours of the experiment. The implementation of tools, which are common in structural mechanics, has demonstrated that no visible deformations were observed in the prototype but not after 2500 hours of duration of the experiment.

Keywords: Cardboard, Point of Purchase, Integral Model of Design New Products, Extensometry, useful life.

RESUMEN:

En este trabajo de investigación se presenta el estudio de la vida útil del prototipo de un exhibidor de cartón para punto de venta conocido comercialmente como POP (Point of Purchase). El POP propuesto, se emplea como una herramienta de mercadotecnia para distribuir, almacenar y vender 700 envases tetrapack™ de un litro por unidad. Se empleó el Modelo Integral de Nuevos Productos (MIDNP) en su Fase II para crear un prototipo e incluye el diseño industrial, análisis de fallas, análisis de Elementos Finitos (FEM) y evaluación experimental con mediciones de Extensometría eléctrica. Considera también modificaciones en el proceso de manufactura. Durante el experimento, el prototipo fue sometido a carga máxima y analizado durante 3500 horas para identificar su comportamiento mecánico. La importancia de esta evaluación radica en que cuando un POP no se encuentra en buenas condiciones físicas, el proceso de mercadeo se ve interrumpido incluso antes de que se presenten sus fallas mecánicas, su vida útil se ve reducida si su efecto visual no estimula la intención de compra del cliente. Como resultado de la aplicación del MIDNP se obtuvo una mejora en un 25% de la vida útil del POP en comparación con otros diseños. El uso de las herramientas comúnmente usadas en la mecánica estructural demostró que no se observaron deformaciones visibles en el prototipo sino hasta después de las 2500 horas de duración del experimento.

Palabras clave: Cartón, Punto de Venta, Modelo Integral de Diseño de Nuevos productos, Evaluación estructural, POP.

1. INTRODUCTION

Cardboard as an engineering material has been used in a diverse variety of applications, not only to manufacture boxes, but also as a key material for the distribution, packaging and for the storage of products. It can be used also as a great value tool for example, when it is used for marketing to products display attractively and have the ability to increase the desire to purchase. In addition, its acoustic, thermal and biodegradable properties have been used as a low-cost technological solution [1-2]. It offers the advantage to be reused in ecologically friendly applications after partial or total recycling when it reaches the useful life [1-4].

The characteristics and appearance of the packaging in food products has a direct influence on the purchase decision, its geometry and the combination of colors predominate in the perception of the product and in the mental decisions that the client conceives at the instant of purchase [5, 6]. The association of words on the labels can also have a positive or negative influence for future purchases because the client can have a mental relationship of the packaging of beverages and foods with the benefits to their health [7-9]. These symbolic associations create a subtle impression even in the taste of consumable products [10, 11]. After the useful life of cardboard packages or products, its recycling is important because it offers different benefits compared to the recycling of plastics or metals [12].

Cardboard displays installed in stores and supermarkets have been an excellent option to promote the sale of new products, due to its low cost, ease of use and recycling capacity among other advantages. In these places, purchase decisions are made very quickly. Manufacturing companies and distributors compete constantly to improve their sales techniques. Thus, the POP work as "silent sellers", the more attractive they are, the greater the possibilities of selling the product. Attributes such as colors, the arrangement or orientation of the contained products, cleanliness, the sensation of a visual order and physical stability are factors that have an important influence on the purchase decision of the clients [13, 14]. An adequate mechanical analysis of the structure of a cardboard POP is fundamental for the fulfillment of these attributes required in current markets.

2. METHODOLOGY

This research has been developed by applying the concept of the Integral Design Model for the Design of New Products (IMDNP), it has the objective to optimize the product design from the moment of its conception, that is; to consider in an integral way the requirements of design, function, process and delivery of the product. The methodology considers also the customer's needs and it finishes in the recycling and/or life cycles of the final product. As showing in Figure 1, this research is limited only to the results of Phase II-product of this proposed procedure, which includes the analysis of failure modes, numerical and experimental analysis. The component phases of this methodology are the following:
Phase I. Market: Analysis of customer needs.

Phase II. Product: Conceptual design and sustainable development of the product to obtain a prototype.
Phase III. Process: Process design, planning and cost relation for manufacturing and logistics.
Phase IV. Organization: Supply Chain, Operations Management, Logistics and Feedback of market conditions, recycling, product life cycles and continuous improvement. On each of these phases, an added value for the POP is obtained. Figure 1 shows the distribution of activities carried out in the IMDNP.

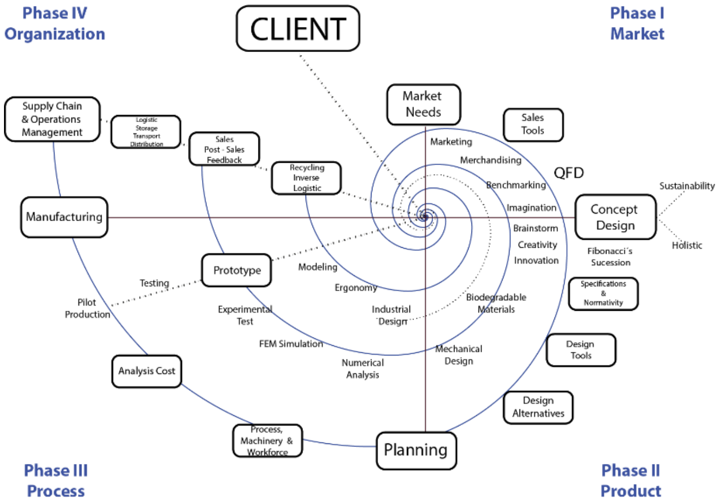


Fig. 1. Integral Model for the Design of New Products (IMDNP)

For the purposes of this study, emphasis is placed on Phase II of the product, which consists in the analysis of customer's requirements, using the Quality Function Deployment (QFD) methodology. According to the obtained results, the conceptual design is developed based on the sustainability and holistic principles. Subsequently, design alternatives are proposed, followed by an evaluation of the proposals that meet the highest value requirements; considering the specifications and regulations that the product requires. In addition, it is required to visualize the following product processes, planning, manufacturing, cost analysis, supply chain, distribution, logistics and reverse logistics. In order for the conceptual design to meet the desired objectives, it is important to achieve the existing synergy in all the product processes before reaching the mechanical design process and the development of the prototype. This phase was applied in the design and monitoring of a real POP at the point of sale considering the manufacturing process and the mechanical behavior.

Based on field research in cardboard POP manufacturing companies, 100 surveys were conducted on the useful life of cardboard exhibitors, the target audience were manufacturers and users of cardboard exhibitors, they play an important role as promoters in stores. It was found that only 50% of the installed POP have been in optimal working operation and for less than 1 month, showing rapid deterioration. Most commercial chains require a minimum life of 3 months for the POP at the point of sale. A series of internal and external problems were identified in these companies, which affect their ability to quickly respond to the requirements of their clients. Internal factors are related to procedures within the company and may or may not provide a rapid response when they have to face seasonal changes in the market. The external factors are related to the type of product that is sold through the POP. Both elements must coincide to comply with a fast and economically sustainable manufacturing process that provides added values to the presentation of the product. It is very important to emphasize that the POP is one of the last links in the chain of sale of the exhibited product. During this final stage, the mechanical structure must withstand with sudden movements and impacts and these must also be considered to reduce the chances of failure since the POP is not only used as part of the packaging but as a main element in the transportation, distribution and final storage of the products.

2.1. CRITICAL FAILURE MODE ANALYSIS

The critical failure mode analysis [15-17] is shown in Table 1 and compares 3 different cardboard POP installed in the market and identified as D1, D2 and D3. In this case, the mechanical failures are related to the load capacity, maneuverability and safety. It was found that the ergonomic elements must also be considered to avoid situations in which the client suffers from some damage during the process of taking products. Aesthetic failures are related to the deformations that the client perceives with their senses and that also damage the purchase intention.

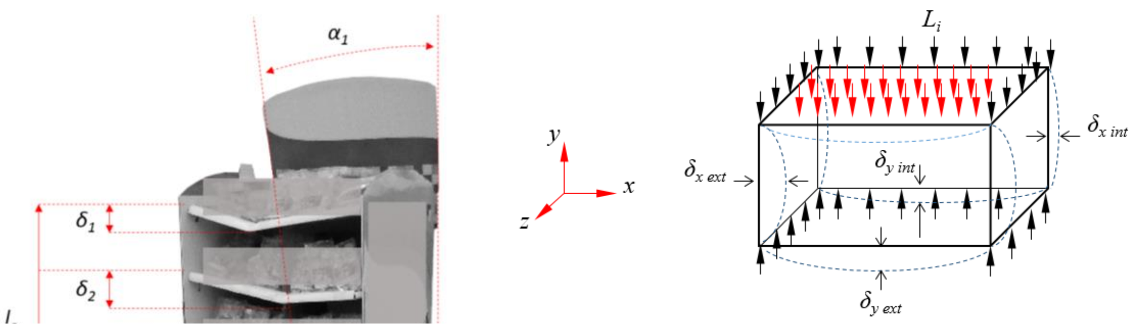
ID	Exhibited Product	Potential Failure Mode	Potential effects after failure	Type of failure	Potential causes of the failure
D1	Clothes	Tilt	Exhibitor Drop down Product drop down Damage to customers Decrease in sales	1	Design errors
				1	Excess load
				1	Fatigue of the material
				1	Manufacturing errors
				2	Environmental conditions, Assembly Errors
D2	Cookies	Deformation of the central panels	Decrease in POP attractiveness	2	Incorrect selection of materials
			Decrease in sales	2	Load calculation errors
			Mishandling of products	1	Excess load
			Product failure	1	Design errors
			Damage to customers	2	Operation errors, bad assembly
			Customer demand	3	Product errors Excess load / pressure when packing
D3	Glass Refractories	Deformation of the central panels	Reduction of product rotation	2	Incorrect selection of materials
			Product failure	2	Incorrect load calculation
			Mishandling of products	3	Excess of product
			Decrease in POP attractiveness	2	Design errors
			Decrease in sales	2	Operating errors-poor assembly
			Product waste	3	Production errors

Table I. Failure Mode Analysis in POP Displays.

2.2. IDENTIFICATION OF THE POTENTIAL FAILURE MODE

Based on the comparative failure analysis, the following important potential faults were found: a) Inclination of the POP and b) buckling in the central and lateral panels. The possible causes that generated these failures are errors in the design, excessive loading, errors or failures related to the product, errors of the operators during the assembly of the merchandiser, and errors during the process of packaging the product. Figure 2a shows the model named D2 as one of the most representative examples of failures found in a typical cardboard POP. Gray rectangles were used to cover the brands and labels of the product since the images shown are only used for the academic research intention. By observing the failures in this and other types of cardboard POP, changes were generated in the traditional process of its design and manufacture with the purpose of making improvements that increase its load capacity, reduce its assembly time and increase its useful life. In the design shown in Figure 2a it is observed that the original height of the POP remains stable, however the angle of inclination that maintains with respect to the vertical $\alpha 1$ creates an image that drastically reduces the purchase intention of the contained product. The individual displacements of each floor are notoriously increased so that $\delta 1 > \delta 2 > \delta 3$. This compromises the integrity of the product increasing the damage on each floor obtaining, for example, damaged products inside, even the fact that its packaging is in good external condition. This buckling situation of the POP ($\alpha 1$) also compromises the buyer's safety.

Figure 2b shows a general case of load distribution in each of the floors with respect to an x, y, and z coordinate system located at the floor level of the panel. The sidewalls suffer a δ deformation when the structure is supporting the entire load, in such a way that δx ext > δx int and δy ext > δy int, which corresponds respectively to the internal and external deformations of the walls.
In this case, Li represents the load on each floor and comprises the weight (Wb) of a bottle multiplied by the total number of bottles on each floor, plus the weight (Wc) of the portion of cardboard. The position of each bottle can be located with respect to a n(x,y) coordinate in the floor.



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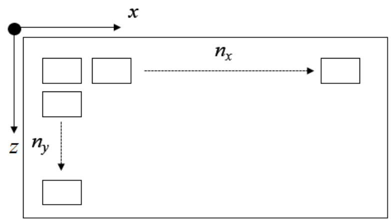
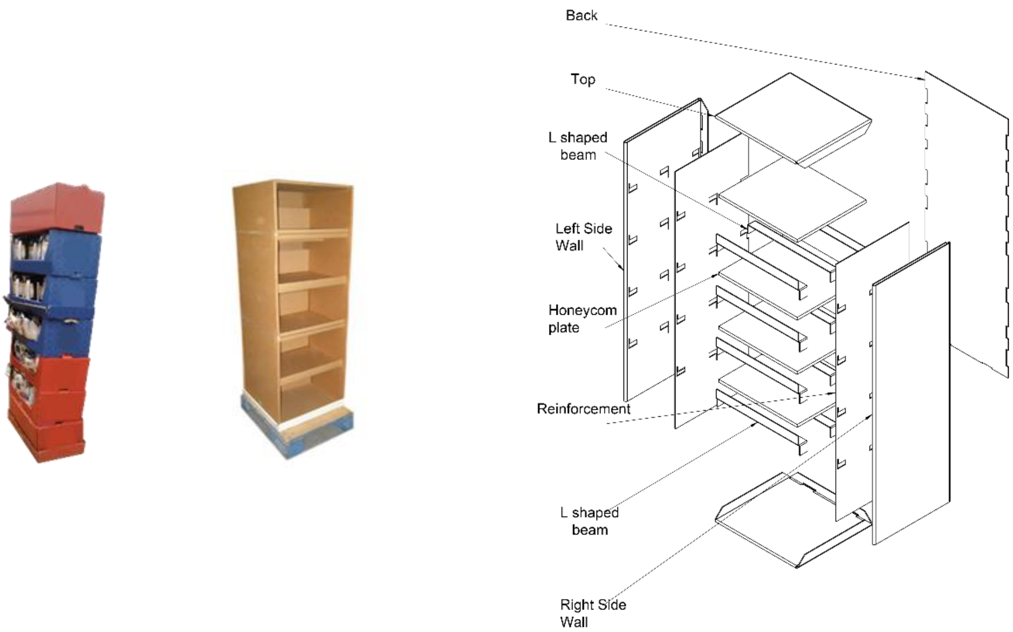


a) c)

Fig. 2. Mechanical deformations in a typical POP, a) typical failure, b) Boundary conditions, and c) location of the load in each floor.

3. RESULTS

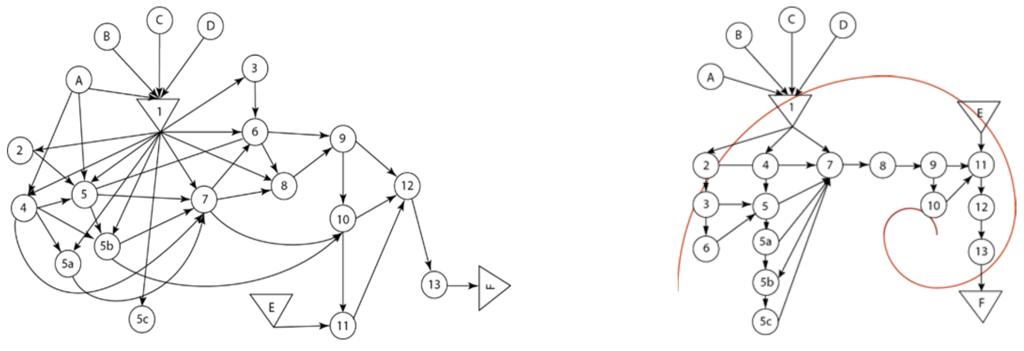
From the failure analysis and the obtained results, the necessary requirements were registered and analyzed to create the proposal of the new POP design. Applying the IMDNP, a modular prototype was developed, resistant with a strong structure and easy to assemble. Figure 3 shows the comparison of two POP. Figure 3a shows a traditional POP manufactured by the company, Figure 3b shows the resulting new proposal, being constituted with plates and cardboard beams to provide structural reinforcement in the loading areas, a backrest wall and two double sidewalls (see Figure 3c). For each floor, a honeycomb cardboard plate was used and reinforced in the bottom side with an L-shaped cardboard beam.



a) b) c)

Fig. 3. Comparison of a) a previous POP model, b) the redesign and c) the components of the redesign.

For each type of cardboard component, stress, compression and bending tests were carried out considering the direction of the load that each piece should receive and according to their position in the prototype. With the application of the IMDNP, the manufacturing process was modified with respect to an original one. After monitoring the manufacturing of 400 POP, the time for each activity was registered. The traditional model required 124 working days and the modified process takes only 64. The comparison of both sequences is shown in figure 4a and 4b and the corresponding list for each activity is shown in Table 2.



a) b)

Fig. 4. Sequence of a) the traditional manufacturing process and b) the resulting methodology.

		Traditional Model			IMDNP implementation		
Id.	**Description**	**Quantity**	**Time**	**Symbol**	**Quantity**	**Time**	**Symbol**
		pieces	days		pieces	days	
1	Raw material	9052	15		6148	9	
2	Cut	10400	7		6400	3	
3	Print	6000	8		2000	4	
4	Die	10800	11		4800	3	
5	Cutting	10800	6		4800	6	
6	Glued	6400	6		2800	4	
7	Finish	6400	5		5600	5	
8	Assembly	10400	9		6000	5	
9	Warehouse	11600	6		6400	3	
10	Prod. reception	179200	10		278400	10	
11	Fill	400	7		400	4	
12	Packaging	400	7		400	4	
13	Shipment	400	7		400	4	
	Total	**262252**	**124**		**324548**	**64**	

Table 2. Modified stages of the traditional POP manufacturing

As shown in id 10 of Table 2, from 179,200 to 278,400 finished products were achieved with the implementation, representing an increment of 55%.

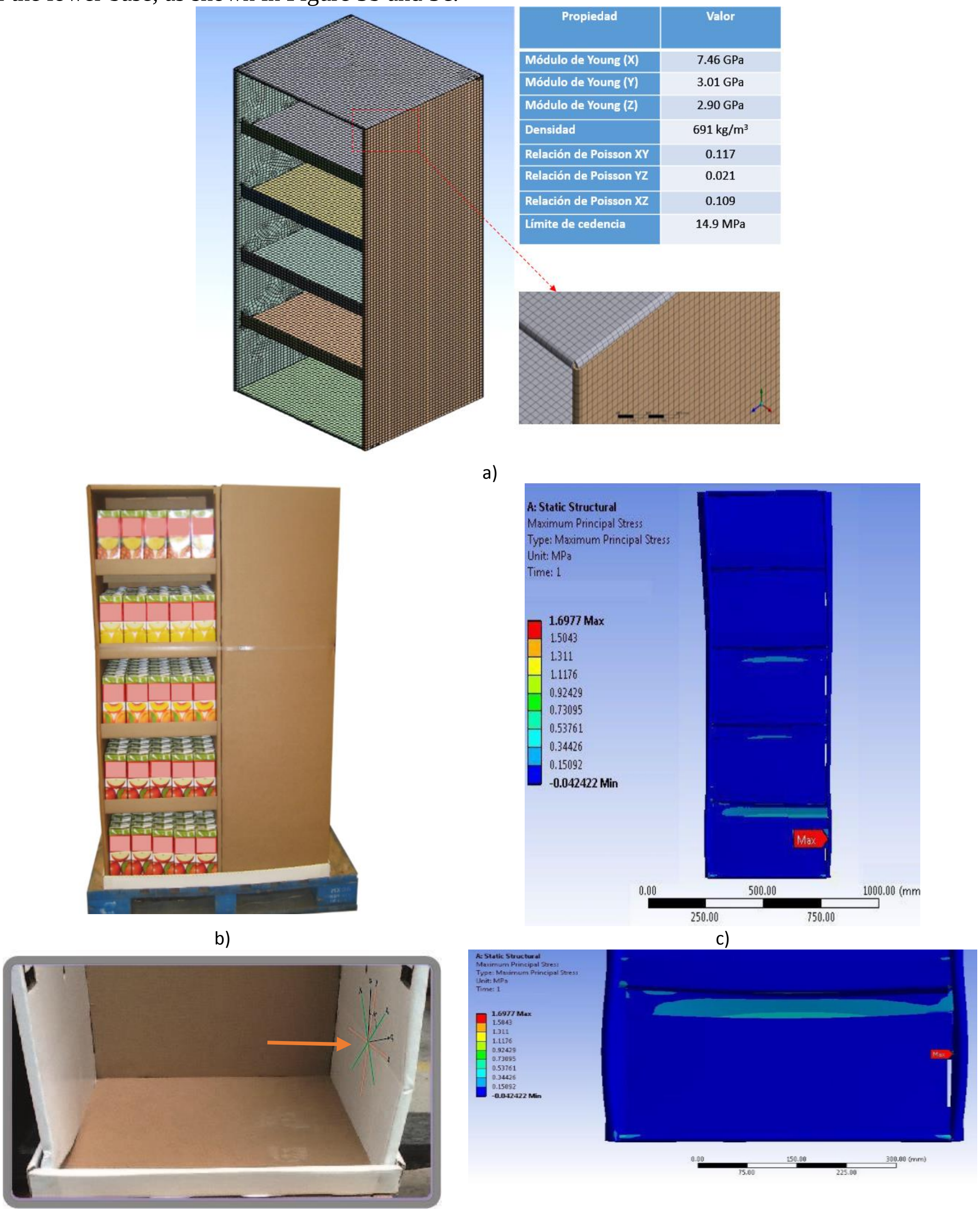
4.- EVALUATION OF MECHANICAL BEHAVIOR

The cardboard prototype was instrumented with strain gauges located in the following positions: a) under the beams, b) near the joints and c) in the center of the plates (in the lower side). The experiment consisted in completely filling each one of the floors, with 35 products in each level, in the same way it is presented in stores. The POP was placed inside a room isolated from humidity with a temperature of 20° C.

A daily register of the gauges was made during 6 months. The mechanical properties of the cardboard components were obtained with a Shimadzu®AG 250kN universal tension machine [18] and the samples were obtained following the ASTM-E8 standard.

The mechanical properties obtained were used as input data in the numerical model shown in Figure 5a. This model is composed of 149,867 elements and 787,675 nodes and includes the cuts and bends that were made in the real prototype.

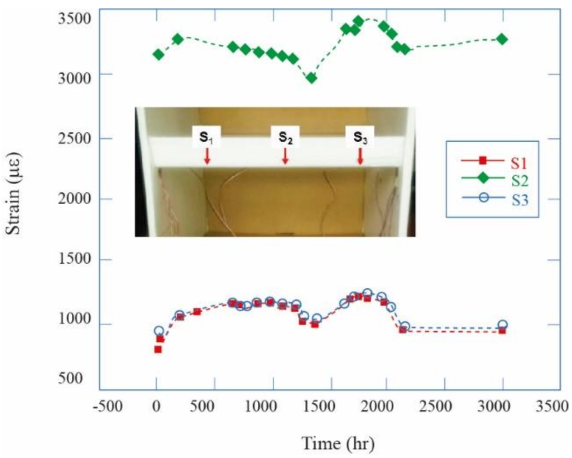
The load produced by the weight of the products added a total of 175 liters per POP. The bottom side of the POP (Figure 5d and 5e) was restricted along the x, y and z axes. The magnitude of the maximum principal stress observed was 1.69 MPa located on the outer face of the sidewall of the first floor. The backrest wall also suffered a horizontal displacement due to the concentration of stresses whose values were between 0.3 and 0.7MPa. Both the numerical and experimental analysis, shown a maximum displacement of 15 mm located in the top side of the POP with respect to the position of the lower base, as shown in Figure 5b and 5c.



Propiedad	Valor
Módulo de Young (X)	7.46 GPa
Módulo de Young (Y)	3.01 GPa
Módulo de Young (Z)	2.90 GPa
Densidad	691 kg/m³
Relación de Poisson XY	0.117
Relación de Poisson YZ	0.021
Relación de Poisson XZ	0.109
Límite de cedencia	14.9 MPa

Fig. 5. a) Numerical model and material properties, b) POP supporting the maximum load, c) location of the maximum stresses, d) real distortion observed at the base of the POP after 2500 hours and e) distortion obtained in the numerical analysis.

Figure 6a shows the deformations registered in S1, S2 and S3 gauges throughout the experiment. It was observed that the S1 and S2 gauges registered values of 792 and 950 με when loaded, at the end of the 3500 hours the value was 950 and 970 με in tension (respectively). That indicates an acceptable structural stability. The S3 gauge recorded a high value deformation, starting with 3176 and finishing with 3201με. In the S4 gauge, a high compression value was registered at the end of the experiment, which coincides with the behavior of the S3 gauge and the registers shown in Figures 5c and 5e. In the case of the S5 gauge that corresponds to the plate, an initial value of 1332 and a final value of 486μ was obtained, which indicates extreme flexion in the honeycomb plate when loaded and subsequently recovered and remaining stable. The values of the main stresses determined by the rosettes (R1, R2 and R3) achieved a maximum of 1768 MPa and a minimum of -0.054 MPa and their corresponding deformation values are shown in Figure 6d.



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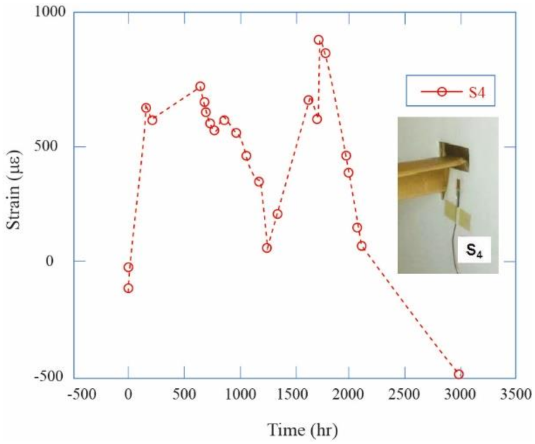

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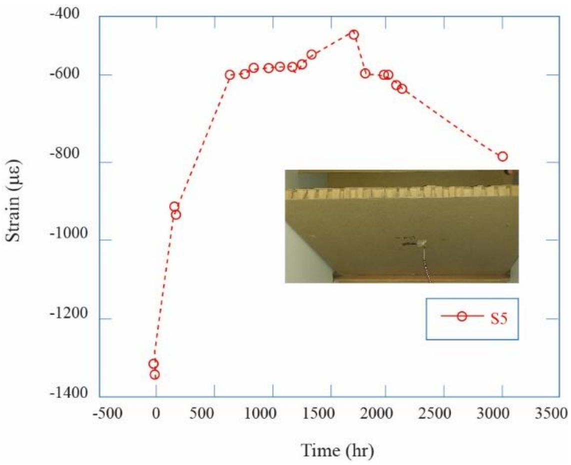

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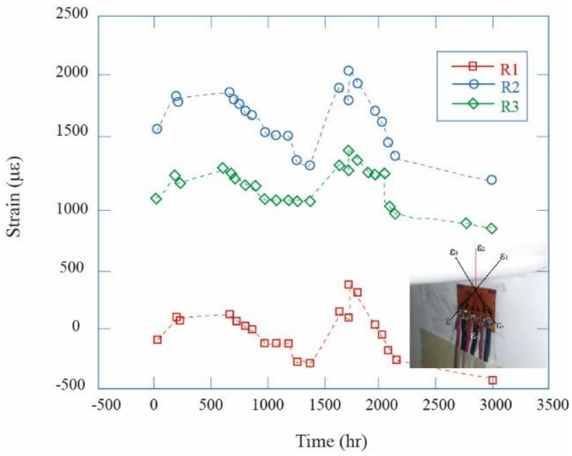

d)

Fig. 6. Distribution of the deformations throughout the 3500 hours of the experiment for the gauges a) S1, S2 and S3, b) S4, c) S5 and d) R1, R2 and R3.

Table 3 shows the relationship between the measurement time, the obtained deformations and their corresponding stress values during the experiment.

Gauge	Time (h)	Unit deformations µm		Stress
		Start	End	(MPa)
S_1	1724	880.00	938.00	1.31
S_2	1952	950.00	959.00	1.33
S_3	1724	3176.00	3287.00	4.6
S_4	1724	-134.00	-492.00	-4.11
S_5	1352	-1306.00	-486.00	-11.17
R_1	1352.15	-66.00	-429.00	1.666
R_2	1070	1638.00	1203.00	-0.089
R_3	1724.15	1043.00	815.00	-

Table 3. Unit deformations and main stresses

Table 4 shows a comparison between the experimental and the numerical analysis results (FEM), Figure 5d and 5e respectively.

	Principal stress		Displacement
	Experimental	FEM	
	(MPa)	MPa	mm
Maximum	1.660	1.6977	0.145
Minimum	-0.089	-0.042	0.016

Table 4. Experimental and numerical results.

Tables 5 and 6 show the indicator values used in the failure mode analysis and are necessary for interpretation of the results shown in Table 7. Table 7 shows the results of the failure analyzes of models D1, D2 and D3 in comparison with the D4 prototype that was designed using the proposed IMDNP methodology, a risk priority number (RPN) was also assigned. The scale assigns a degree of severity that goes from 1 to 1000 in which, 1 indicates a consequence without effect and 1000 indicates a serious consequence. Similarly, a value was assigned to observe the occurrence frequency. To calculate the detection value, a probability range was considered from the highest to the least probable. According to these results, the D2 model is considered to have the highest risk while the D4 presented the lowest risk.

Figure 7 shows a comparison of the time it takes to appear a structural failure in each of the POP considered from D1 to D4. These time registers were taken considering the failure as a criterion in which the POP no longer fulfills all the initial characteristics.

Id.	Potential effect of the failure	Value
1	Exhibitor Drop down	A-EP-01
2	Product drop down	B-EP-02
3	Damage to customers	C-EP-03
4	Mishandling of products	D-EP-04
5	Decrease in POP attractiveness	EP-05
6	Structural deformation due dynamical loads	F-EP-06
7	Deformation on the panels	G-EP-07

Table 5. Value indicators of the Potential Failure Effect

Id.	Potential causes/failure mechanism	Value
1	Excess load	I-CP-01
2	Design error	II-CP-02
3	Bad Assembly	III-CP-03
4	Production Errors	IV-CP-04
5	Environmental conditions	V-CP-05
6	Incorrect selection of materials	VI-CP-06
7	Packaging errors	VII-CP-07
8	Stress Concentration in lower section	VIII-CP-08
9	Height of the POP	IX-CP-09
10	Structural design of the supports	X-CP-10
11	Fatigue of the material	XI-CP-11

Table 6. Value Indicators of the Potential Causes of Failure

Item	Function	Potential Failure Mode	Potential Effect (s) of Failure	Sev	Class	Potential Causes (s)/Mechanism of Failure	Ocurr	Current Design Controls	Detec	RPN	Recommended Actions	Action Results				
												Actions Taken	Sev	Occ	Det	RPN
D1	Garment display	Inclination	EP-01	10		CP-03	9	Design Analysis	3	90	Adapt the assembly		10	9	0	90
						CP-03	7						10	7	0	
			EP-02			CP-11	5						10	5	0	
						CP-04	4						10	4	0	
						CP-05	3						10	3	3	
D2	Cookies display	Deformation of the central panels	EP-01	10		CP-01	10	Detailed analysis of the design	10	1000	Experimental analysis of the pilot prototype in plant and field	Evaluate pilot prototype at the point of sale	10	10	10	1000
			EP-02			CP-03	10						10	10	0	
			EP-03			CP-03	10	Analysis and testing of new materials					10	10	0	
			EP-04			CP-04	9				Evaluate dynamic and static tests of the pilot prototype		10	10	0	
			EP-05			CP-05	9	Inspection of the production process					10	9	0	
													10	9	0	
D3	Display of glass refractories	Deformation of the central panels	EP-01	10		CP-01	10	Design Analysis	8	720	Experimental analysis of the pilot prototype in plant and field	Evaluate pilot prototype at the point of sale	10	10	0	720
			EP-02			CP-03	10						10	10	0	
			EP-03			CP-06	10						10	10	0	
			EP-04			CP-03	10	Analysis and testing of new materials			Evaluate dynamic and static tests of the pilot prototype		10	10	0	
			EP-05			CP-04	9						10	9	8	
						CP-05	9						10	9	0	
D4	Tetrapack Display	Deformation on the sides	EP-06	3		CP-07	8	Structural design evaluation for improvement	1	9	Identify points to be reinforced in a pilot prototype	Prototype manufacturing with reinforced points	3	8	0	9
						CP-08	4						3	4	0	
			EP-07			CP-09	3						3	3	1	
													3	3		
			EP-02			CP-11	3								0	

Table 7. Comparative results of the failure mode analysis of the considered POP.

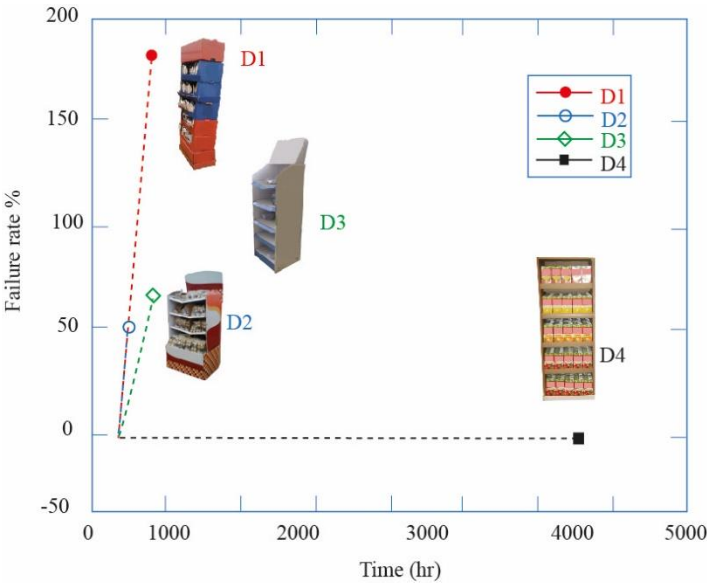

Fig. 7. Time of failure occurrence with respect to the appearance of the failure

5.- DISCUSSION

Establishing fault criteria is an activity that may be subject to compliance with product handling and packaging standards, especially food products and beverages. In addition to these, other criteria related to the aesthetics of the product and its impact on the purchase intention can be considered as failure elements. Both are related to the structural integrity of POP. The actual operating conditions of cardboard POP can vary in each store, for example; the presence of humidity in the environment or a spill of liquid in the base of the POP would make to appear failures in the integrity of the cardboard. The abrupt handling of the products, occasional hits caused during the taking of the products, the placement of excessive load, etc., are some of the factors that make POP to present failures in a very short time. In some other cases where the POP is less exposed, the time of occurrence of faults could be extended. However, it is important to identify that when applying the techniques of mechanical analysis to this type of POP, its useful life is considerably prolonged. The direct benefit can be observed in a saving of materials and processing of cardboard manufacturing by delaying the appearance of faults, the speed of growth of cardboard waste is also reduced which together with an adequate recycling process, can directly benefit the conditions of the environment.

6.- CONCLUTION

In this work, the useful life of 4 cardboard exhibitors known as POP was analyzed. Even if they are able to hold the products, the most common physical faults that occur with conventional designs are associated with the deformation of their supports. The mechanical stability of 3 of them is lost before reaching 1000 hours at full load operation. This condition affects the aesthetics of the POP and reduces the impulse of purchase, in some cases; this condition can generate a damage to the product. With the implementation of the IMDNP methodology, the POP prototype presented, achieved sufficient mechanical stability and resistance for 4500 hours under full load. This is 5 times more with respect to conventional designs. The experimental results show that they agree with those obtained in the numerical analysis. In the proposed prototype, the maximum stress concentration was found on the bottom of the sidewalls, but no damage was seen in the exhibited product. The results presented here can be used as a reference in future cardboard POP designs obtaining some of the benefits mentioned in this research.

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