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RETROSPECT OF THE INFLUENCE OF TRANSPORTATION IN THE DELIVERED QUALITY OF PALLETIZED PRODUCT

Abstract: *Palletizing products consist on the most prevailing method of packaging for wholesale merchandise in diverse industry sectors given its compact shape proper for transportation and storage. However, the arrival of damaged goods to retail still is a common scenario, representing a significant impairment to both retailer and manufacturer due to a poor-quality end product for the consumer. Within the complex supply chain involved in palletized products, transportation is the main responsible for maintaining their integrity, representing also the majority of all logistic costs involved. Given the financial impact that quality enhancement technologies can cause in this embracing packaging sector, the present study intends to review the main aspects of harmful transport-inherent mechanisms such as vibrations, shock and sloshing, exploring also numerical modelling techniques and establishing a baseline for quality conveyance through a brief literature review.*

Keywords: *Packaging, Pallet transportation, Finite Element Analysis, Random Vibration, Sloshing*

1. Introduction

A supply chain encompasses all activities in fulfilling customer demands and requests. The development of supply chain management techniques is a progressive and prolific area of study, whereas the evolution of products and processes might result in significant gains in terms of efficiency, be it related to feedstock, suppliers, manufacturing or distribution. Further than that, supply chain know-how is not a mere market advantage, but a mandatory concept nowadays to companies that look forward holding their market share, once fast shipping of defect-free products in the cheapest viable manner has become a costumer's demand (Mentzer et al., 2001). Coordinate alliances with stakeholders are a key factor for achieving a total quality management (Fragassa et al., 2014) of the supply chain and the development of more efficient products and processes (Urban & Toga, 2017) where intelligent manufacturing systems have already shown to be very valid in other application fields (Djapic et al., 2017); yet providing a competitive advantage through the costumer value formation (Langley & Holcomb, 1992).

The role developed by transportation in a supply chain is crucial, being not only responsible for carrying palletized goods from the producer to the consumer on a just-in-time basis (Sayer, 1986), it also has to maintain the integrity of products on a safely conducted conveyance. In average, the costs with transportation represent 20% of all production costs (Russell & Taylor, 2013),

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reaching in some cases over 50% of the total logistics budget (Pedersen & Gray, 1998). Hence, improving the efficiency of transportation aspects reflects on escalating not only external income, consolidating and expanding market share, but also internal finances, due to the cost reduction already foreseen in the company's budget. One of the main issues regarding transportation is that the sector is the most responsible for damaging products, which represents a direct financial loss due to the wasted merchandise, including and indirect one by deteriorating the product's brand image for the final consumers. It is a reality that many products arrive on the retailer damaged enough to be considered unusable where the waste of unsaleable defective products is estimated to cost approximately 15 billion dollars a year to the industry worldwide (Grocery Manufacturing Association, 2008).

Selecting the transport mode choice and carrier are an important part of the logistics planning process, where it is necessary to identify and deal with variables such as shipping distance, expected delivery time, conveyance rates and carrier performance (Monczka et al., 2005). Ironically, the most used modal transport in the globe is the same that has the higher rates of traffic accidents, cargo theft and damaged products: truck conveyance. Overall, this modal is used more often than trains, ships or airplanes (Fragassa et al., 2017), because most emergent or undeveloped countries do not have a sufficient alternative infrastructure (Moljevic, 2016) such as railways, ports or cargo airports. The reason for not having maritime or fluvial transport might also be as simple as for the country being geographically disadvantaged, with no seashore or rivers. However, lobby politics and tax incentives to the automotive industry are still a reality in the current economic scenario, where large extension countries such as Brazil that could be extremely benefitted from a developed rail network, has a commercial transport predominated by a truck fleet constituted by over 1.7 million vehicles. Naturally, as in every other modal, truck transport has its advantages, being able to reach hard-access regions (Rissi et al., 2008) and having a good cost-benefit relation for short-distance shipments.

The focus on the accommodation of cargos performs a fundamental factor in the process, as handling increases the risk of product damage or loss. Despite the fact that conditioning and handling entail costs for the company, they are essential to assure the integrity of the product. In this context, the concern about cost reduction aims to explore a system of efficient material handling at low cost, as well as the respective protection and packaging of products, which focus on their protection throughout the entire supply chain process. Therefore, packaging appears as one of the major companies investments and as an integral part of success.

Among all types of packaging techniques, palletized products are currently the most widely used for serving numerous industry sector such as pharmaceuticals, food, beverages, hygiene and so on. Offering the advantages of compactness and ease of handling and storage, the products are stacked on top of each other according to a planned layout in order to not cause self-damage, and placed on wood pallet guaranteeing ergonomics for fork-lifting. Then, a polymeric wrapping film is generally applied for assuring that all products within the pallet are safely tighten within the package. The amount of wrapping material used for a reliable transport as well as its pre-stretching conditions are an important topic of study (Fragassa et al., 2017), given that the package may be shipped to a long-term delivery around the globe, being subjected to humidity, temperature and vibration variations, and must withstand such circumstances.

Besides wrapping plastic, cushioning materials are intermediate packaging resources that are also an important study subject in packaging dynamics (Liang et al., 1998), where several different materials on the market are designed to protect the products transported. Corrugated paperboard is a material that stands out, being largely used in packaging design due to its remarkable protective performance and capacity of energy absorption (Wang et al., 2013). There are four predominant types of cardboard structures: single-wave, double-wave, gripper cardboard and honeycomb. Among them, the latter is generally more advised in the case that a significant amount of energy absorption is demanded (Wang et al., 2016).

All the aforementioned protections are applied for the merchandise in order to resist to three main mechanical damage mechanisms (Jarimopas et al., 2007; Kang & Liu, 2010; Lu et al., 2008; Rissi et al., 2008): shocks, vibrations and sloshing. Briefly, shocks stand for conditions in which impact forces act upon the products such as in an abrupt breaking scenario; vibrations are inferred to the products at all times due to conveyance system used and the route conditions (railway, bumpy roads or rough sea); and sloshing is caused when a liquid product displaces inside its own package, generating a force inside the package. All these impairment sources are the main responsible for transport-related damage to products. The present work aims at describing baseline characteristics of protection technologies such as plastic films and cushioning materials, as well as the harming mechanisms of shock, vibration and sloshing; with a particular focus on techniques for numerically modelling their effects for predicting the behavior of products, aiding in the performance of a quality design of safer and more reliable packages.

2. Packaging Materials

Stretch wrap material is essential to unitize the load composed by all products assembled on top of a pallet (Figure 1), whereas its application is automatized by properly designed packaging machines and it can be applied by three main systems: turntable, rotary arm and orbital. The first relies on a rotating base that spins the pallet while the film is applied by a mast with vertical displacement freedom. As for the rotary arm, it is suitable to products that are fragile, unstable or simply too heavy for the turntable, so the film is rotated horizontally over the load. By its turn, orbital systems wrap the product by placing the film on the upper and lower sides of the pallet instead of wrapping the products' arrangement horizontally.

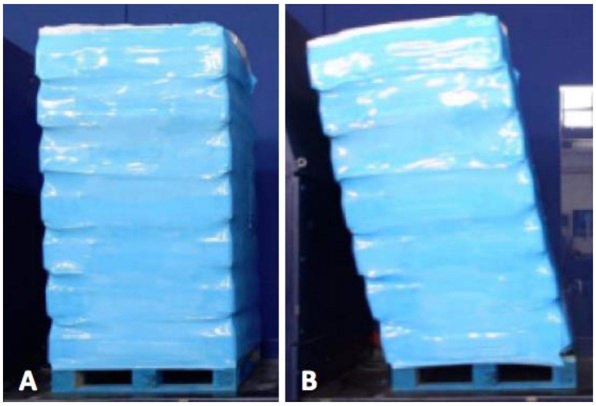

Figure 1. Pallet at rest (A) and accelerated (B). Example of load unitized by stretch wrap: even though the pallet is subjected to an acceleration, the stacked packs of bottles depicted a single-body behavior (Fragassa et al., 2017).

There are several variables to be analyzed when wrapping a pallet in order to provide a safe package design (Singh et al., 2014), such as the wrap pattern that defines the location the film is applied (German, 1998) (generally from bottom to top) and the number of layers used. A proper setting of the turntable and carriage speed are also important: even though one might desire primarily to make the process more efficient and faster selecting elevated turn speeds, caution is advised given that high velocities increase the centripetal force of the load potentially subjecting it to destabilization or film ruptures.

The film type and the force with which it is applied are also a matter of importance. Through pre-stretching, the film is deformed beyond its plastic regime initial threshold by tensioning the film against the package, undergoing strain hardening and raising the already present tensile strength to assure a unitized load. There are two main types of stretch films, blown and cast, and the selection of one of those has also to be made considering that the first provides a more significant load retention, puncture resistance and higher stretch strain limit allowing a higher ratio of cargo covered by length of non-deformed film applied. Cast film has a better clarity, increasing the visual and cargo tracing aspects of reading and scanning.

Cardboard is a very common material for intermediate packaging, protecting and isolating product units from themselves within a pallet, yet providing a certain capability of energy absorption against mechanical shocks, being found in the form of cartons, boxes or trays. Besides the cardboard forms used for containing each product unit such as whiteboard (proper for direct contact with food), the strength and durable solidboard (packages of fruit juices and soft drinks) and the cheap chipboard (outer layers of cartons for foods such as cereal and tea); fiberboard is the one used for making the boxes that are stacked in a pallet. It can be found in both solid and corrugated forms, and its elevated resistance against compression, impact, crushing and abrasion damages makes it suitable for shipping bulk food and retail boxes of general products (Soroka, 1999).

3. Cargo Damage Mechanisms

3.1. Sloshing

Sloshing is the creation of a force by the displacement of a liquid mass, acting when a partially filled container is redrawn from an inertia state by an acceleration: the fluid present in the tank moves to a certain part of the container as a reflect of the movement subjected to it. In some cases, such as in large tanks or in a convoy with dozens of pallets with hundreds of small bottles inside of each, this force created represents a noticeable impairment to the packaging structure also influencing on the transport vehicle stability (Kang & Liu, 2010). The magnitude of this force is determined by factors such as the percentage volume of liquid inside the tank, the geometry of the tank and its motion frequency and amplitude (Akyildız & Unal, 2006; Kang & Liu, 2010). Besides physical factors of the liquid such as density and dynamic viscosity, the sloshing force can be enhanced if there is enough liquid inside the tank to bear a significant mass, but at the same there if there is enough space for it to move freely inside the recipient.

The directions that a liquid can displace inside of a tank are pitching, lateral, parametric, roll, or a mix of them. Furthermore, it is important to highlight the swirl motion (Akyildız et al., 2006), which is the most dangerous one for happening near the first natural frequency of the fluid causing elevated motion amplitudes, thus big sloshing forces. The main device used to avoid this product damaging effect in tanks is the introduction of internal baffles, decreasing the fluid dynamic loads significantly by creating smaller containment zones for the liquid (Kang & Liu, 2010).

3.2. Vibrations

The influence of vibrations in damaging structures is well-known in the more diverse study areas, comprised by precision tools (Pavlovic et al., 2016), automatic machinery (Martini & Troncossi, 2016), woodworking machines (Fragassa, 2017), vehicles (De Camargo et al., 2017) and, naturally, transportation of goods (Jarimopas et al., 2007). As a matter of fact, cushioned packages which are designed to protect a certain product from shocks, might become a major magnifier of vibrations (Jarimopas et al., 2007). Experimental studies are made with the aid of vibration recorders coupled to a GPS, to identify the influence of such damaging source on the shipping route (Rissi et al., 2008; Zhong et al., 2016).

Another factor that must be taken into account is the modal of transport used, once convoy suspension characteristics, vehicle speed, route conditions and load level represent determinant aspect to predict the resulting vibration levels (Kurniawan et al., 2015). The cargo carriage layout is also significant: overloading or placing pallets next to each other with low displacement freedom reduces vibrations; and in trucks, vibrations vary depending on the distance from the wheel axes.

Route characteristics such as the rail type, that varies from country to country, can be seen as a predictable vibration source to which the pallet can be designed to withstand. On the other hand, road conditions are often erratic where the vibrations can be classified as random (Martini & Bellani, 2017). High excitation levels are naturally detected on rough road surfaces being potentialized at high speeds (Zhou et al., 2015), although the low-level vibrations have already demonstrated in previous studies to be more relevant in terms of merchandise damage than high-level ones (Singh et al., 2007). Also, besides amplitude, a dangerous vibration to the transported goods can be characterized by excitations at high frequencies (Fragassa et al., 2017).

3.3. Shock

Impact damage can be caused primarily from sources such as high amplitude vibrations or sloshing, but are mainly attributed to irregularities of road surfaces (Lu et al., 2008), be it due to impact among goods or between packages and the conveyor walls. Road segments that have bumps or demand a shift in direction or velocity such as pedestrian crossings, manholes, curves, and railroad crossings, are major causes of impact. Furthermore, besides transportation-related damage, impairments are often caused by poor merchandise handling in loading, unloading, storing and displaying of products. Technologies used to avoid shock damage are basically intermediate cardboard packaging, as described in Section 2, which is good for energy absorption due to the ease with which is deforms.

4. Numerical Modeling Overview

Numerical models are an important tool on modern industry to validate experimental and theoretical assumptions, providing a detailed visualization of the issue studied and the influence of the diverse variables that have influence over it; being currently recognized as a standard validation method by certification agencies in some sectors. Concurrently, this approach has been also applied on simulations involving palletized goods, given the high complexity of the forces acting on them during transportation.

4.1. Sloshing Modeling

Due to the difficulty of solving analytically the nonlinear boundary of sloshing problems, finite element methods (FEM) represent an alternative tool to solve it with two-dimensional sloshing analysis being capable of representing a real three-dimensional case with precision (Kolukula & Chellapandi, 2013; Abramson, 1966). One way to measure the forces due to sloshing that affect the structure of a container of liquid is by using

Nonlinear External Excitation to build a Liquid Sloshing model. With that, it is possible to achieve an Euler transform 6-degrees of freedom motion equation of the container (Yu et al., 2015), and the use of a moving coordinate system is used to include the non-linearity and avoid the complex boundary conditions of moving walls (Akyildız & Unal, 2006). Previous studies indicate that FEM methods provide representative results of nonlinear sloshing problems: Goudarzi and Sabbagh-Yazdi (2012) obtained similar outcomes between a seismically excited tank experiment and a numerical model, whilst Wang and Khoo (2005) formulated an accurate two-dimensional nonlinear sloshing model successfully. The mathematical formulation of a sloshing situation in which numerical models are based is described below.

A nonlinear sloshing problem in a tank represents a situation in which the liquid develops large amplitudes due to external oscillation leading to imprecise results based on linear theory (Goudarzi & Sabbagh-Yazdi 2012; Abramson, 1966). Considering a two-dimensional tank with width a, and the still water depth h represented by Figure 2, where the global coordinate system is fixed in the center of the water surface when at rest. Assuming an inviscid and non-rotational fluid, the liquid motion can be expressed in terms of velocity potential $ø$ in the fluid domain, governed by the Laplace equation:

$$\nabla^2 ø = 0, \quad (1)$$

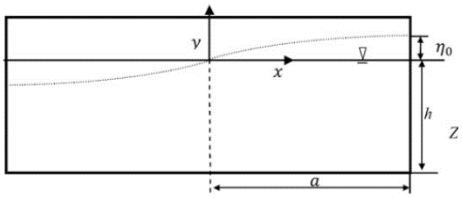

Figure 2. Sloshing of liquid in a rectangular tank (Goudarzi & Sabbagh-Yazdi, 2012)

The velocity component normal to the wall of the tank is zero. Hence, the velocity at the bottom of the tank would also be zero.

$$\frac{\partial ø}{\partial x} = 0 \quad x = \pm a, \quad (2)$$

$$\frac{\delta ø}{\delta y} = 0 \quad y = -h, \quad (3)$$

The dynamic free surface boundary condition on y = η is expressed by:

$$\frac{\partial ø}{\partial t} = \frac{\partial ø}{\partial y}\frac{\partial \eta}{\partial t} - g\eta - \frac{1}{2}[\nabla ø \text{ x } \nabla ø] - \text{x}\ddot{X}_{(t)}, \quad (4)$$

And the kinematic free surface boundary condition by:

$$\frac{\partial \eta}{\partial t} = \frac{\partial ø}{\partial y} - \frac{\partial ø}{\partial x}\frac{\partial \eta}{\partial x}, \quad (5)$$

Where η is the free surface elevation measured from the level of the still water, $\ddot{X}$ the horizontal acceleration of the tank and g the gravitational acceleration. Considering the previous two-dimensional tank, conservation of mass and momentum laws can define the fluid domain. The partial differential equation from these laws can be expressed by:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho V_x)}{\partial x} + \frac{\partial(\rho V_y)}{\partial y} = 0, \quad (6)$$

$$\rho g_y - \frac{\partial p}{\partial y} + \frac{\partial}{\partial x}\left(\mu \frac{\partial(V_y)}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu \frac{\partial(V_y)}{\partial y}\right) = 0 \quad (7)$$

Where V_x, V_y, g_x and g_y are components of velocity and acceleration due to gravity in the axis x and y, ρ is the density and μ is the effective viscosity of fluid (Munson et al., 2009).

These equations are then discretized of finite element based technique, consisting in deriving the element matrices to put together the matrix equation; where a FEM approach divides the fluid domain in a mesh, composed by many elements (a commonly adopted element used for this type of problem is the four-noded isoparametric quadrilateral element) (Goudarzi & Sabbagh-Yazdi, 2012;

Kolukula & Chellapandi, 2013; Wang & Khoo, 2005). A typical mesh composed of these elements it is shown in Figure 3.

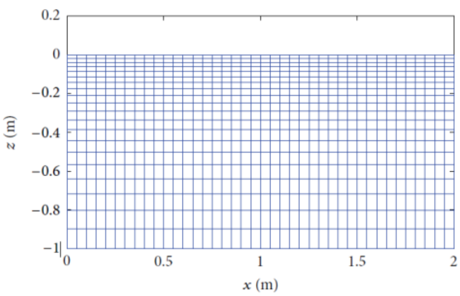

Figure 3. A mesh composed by isoparametric four-noded elements (Kolukula & Chellapandi, 2013)

Popov et al. (1992) performed a study of liquid sloshing in rectangular road containers with different liquid depths, focusing on breaking-acceleration maneuver and a steady cornering maneuver. The study was developed by computational numerical solution based on Navier-Stokes and the free surface equation and experimental results from a small-scale tank (0.8x0.3m and 0.57m of height) displaced by an electrohydraulic actuator. With good agreement between numerical and experimental methods, the results showed that the most intense sloshing occurs when the tank is approximately 30 to 60 percent filled and the forces tend to decrease the fuller the tank gets.

Nicolici and Bilegan (2013) made another study focused on the sloshing excited by an earthquake time history. By using the ANSYS software they combined a computational fluid dynamic (CFD) with a finite element stress analysis (FEA) to predict not only the amplitudes and convective mode frequencies but also the pressure exerted on the wall of the tank by the sloshing phenomenon, Figure 4. The idea of combining CFD and FEA showed reliable results of impulsive pressure on the wall and indicating feasible results for tank geometry with internal structures even with inhomogeneous two-phase model.

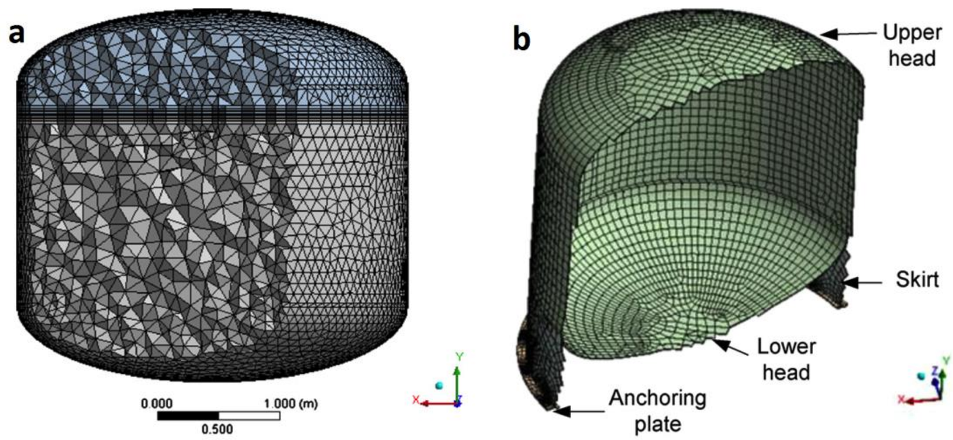

Figure 4. (a) fluid domain mesh, (b) view of the tank FE model (Nicolici & Bilegan, 2013)

4.2. Vibration Modeling

The constitution of numerical models to predict vehicle vibrations is made to validate and supplement statistical data supplied by motion sensors on an experimental analysis. The FEM software ANSYS seems to be the preferred by authors to perform these studies (Liu & Meng, 2014; Yu et al., 2011) permitting five types of analyses: modal, harmonic, transient, spectrum and random vibrations. To define the most suitable, it is important to highlight that many common processes result in random vibrations, such as parts on a manufacturing line, airplane flying or taxiing, spacecraft during launch and vehicle traveling on a roadway (Morgan, 2015).

According to ANSYS inc. (2009), random vibration analysis is a spectrum analysis technique based on probability and statistics, which is meant for loads that produce different time histories during every launch. Using statistics, the sample time histories are converted to Power Spectral Density function (PSD), a representation of the load time history, computing the probability of different results, such as displacement or stress. An internal combination is done to compute the combined effect from each mode and their interactions. The inputs in ANSYS are the natural frequencies and mode shapes from a modal analysis, as well as single or multiple PSD excitations applied to ground nodes. The numerical procedure is shown in Figure 5.

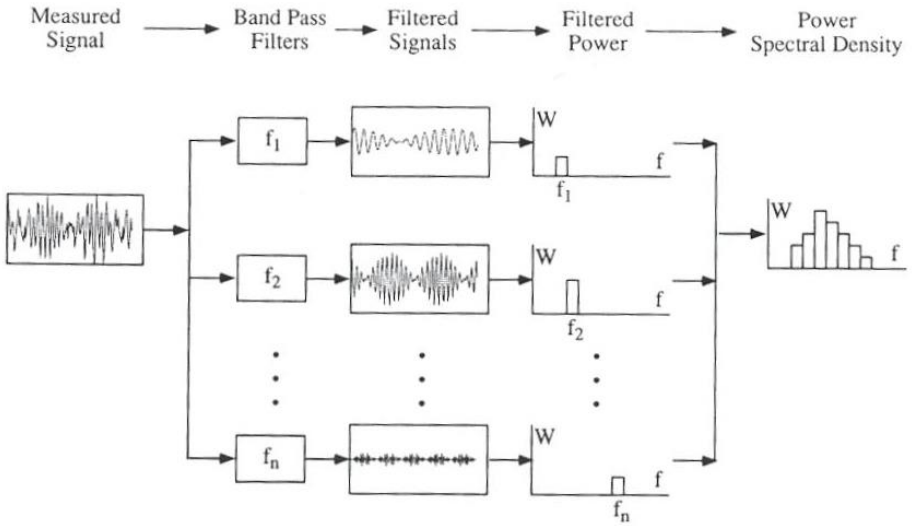

Figure 5. Spectral analysis procedure using analog filter (ANSYS inc. 2009)

When creating a random vibration model in ANSYS, some assumptions and restrictions regarding the structure and the process are taken into account. The structure has no random properties, no time varying stiffness, damping or mass, no time varying forces, displacement, pressures, temperature applied, and light damping. The random process is stationary (does not change with time) and ergodic (one sample tells us everything about the random process) (ANSYS inc. 2009).

The step-by-step procedure to accomplish a random vibration analysis in ANSYS is described in (ANSYS inc. 2009). First, it is necessary to drop a modal system into the project schematic, followed by the random vibration system onto the solution cell of the modal system. After generating the geometry and verifying the materials, connections and mesh settings, it is time to choose the number of modes to extract. The next step is the preprocessing, which is done by inserting the acceleration, velocity or directional PSD base excitation and setting the boundary condition, load data and direction. After that, there is only left the post processing.

In (Yu et al., 2011), researchers developed a FEM to analyze fatigue life of electronic components under random vibration loading. In order to develop this work, a sample of these products was mounted to an electro-dynamic shaker, which was subjected to different vibration excitation at the supports. Using accelerometers and dynamic signal analyzer, it was possible to record time-history data of both the shaker input and the product response, and to obtain the transmissibility function of the test vehicle. After that, a model developed in ANSYS was used to predict the stresses and the lifetime of the electronic components under analysis. The high-cycle fatigue life prediction procedure is shown in Figure 6. The 3D FEA model was first verified through natural frequencies, mode shape and transmissibility function. The volume- averaged stress was then obtained from harmonic analysis from the FEA model. Together with the number of fatigue cycle results from sinusoidal test, an S–N curve was generated. Random vibration was performed both numerically and experimentally. Volume averaged PSD was extracted from FEA model to produce the time-history data. Rainflow cycle counting and modified Miner's rule were applied to estimate cumulative damage of the critical solder joint. In order to validate this model, the same inputs used in the shaker were used as input to random vibration simulation in ANSYS. The FE model was successfully validated by correlating with the natural frequencies, mode shape and transmissibility function from the vibration tests. Also, the FE model showed a good fatigue life prediction.

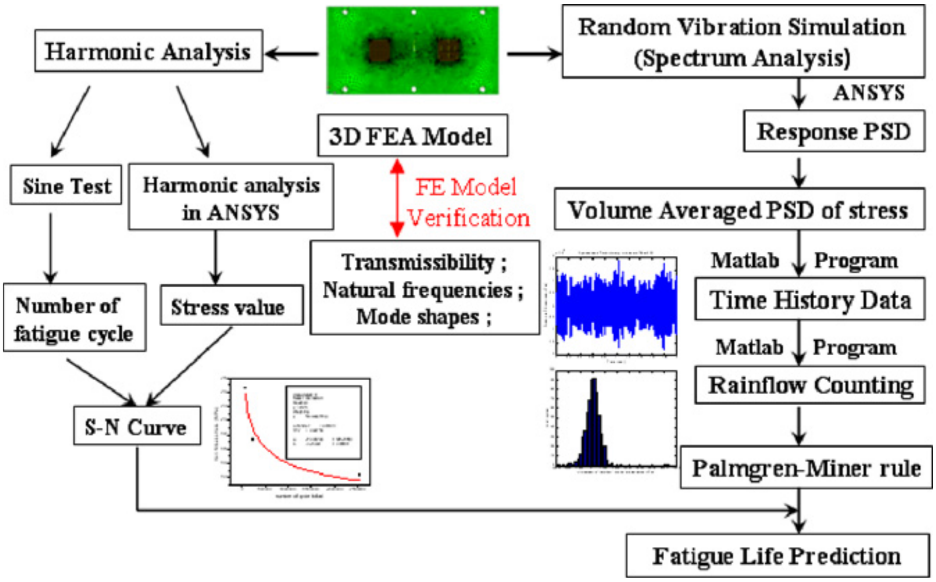

Figure 6. High-cycle fatigue life prediction (Yu et al., 2011)

The reason why (Yu et al., 2011) made use of Finite Element Analysis was because of the difficulty of measuring the stresses in the element under analysis due to its small size (Figure 7a). The FEA model in this work was constructed with the commercial software ANSYS 11. Solid element (SOLID45) was used to model all components in this model (Figure 7b). The boundary conditions were represented exactly like the ones used in the vibration test. In high-cycle fatigue studies, the deflection, stresses, and strains are estimated with the assumption with elastic response; therefore, linear elastic material properties were applied in this numerical model.

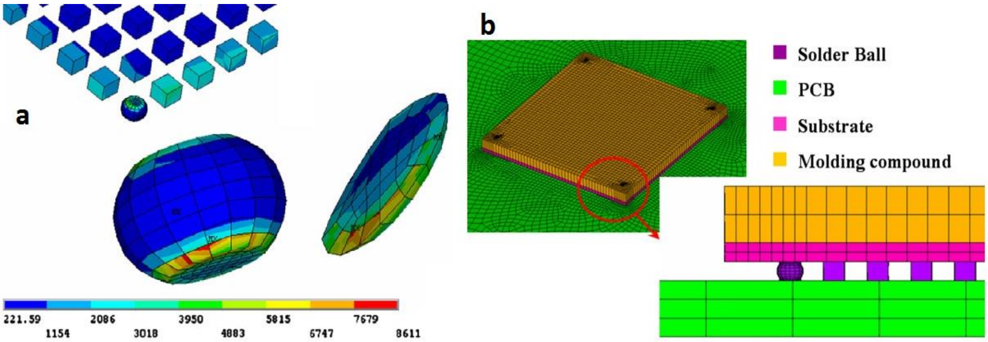

Figure 7. (a) Equivalent stress distribution on solder balls, (b) 3D finite element model of the BGA package (Yu et al., 2011)

In yet another study, more related to the present research topic, a generic linear numerical quarter-vehicle model was developed to compute the vertical vibration level of typical vehicles on different pavement profiles at pre-determined constant speeds. The most basic models are represented by a second-order, two-degrees-of-freedom, linear differential equation, whereby the vehicle response is computed for the vertical orientation with the pavement irregularities as the excitation function. The numerical model developed in this work can account for variations in vehicle speed that can be prescribed by the user. The software effectively computes the solution to the coupled two degrees of freedom second order differential equation using a fixed step solver. There are two inputs that the user should provide: the longitudinal pavement profile, and the vehicle parameters along with velocity schedule. The simulation makes a prediction of the vertical body acceleration for the journey and produces a vibration history in either the temporal or spatial domain. This work showed that a numerical vehicle model in conjunction with measured pavement profiles can be used statistically to obtain accurate estimates of the vibratory response. This approach, illustrated by Figure 8, has the advantage that measured pavement profiles are regularly collected by road agencies around the world and can be used for simulation purposes (Rouillard, 2008).

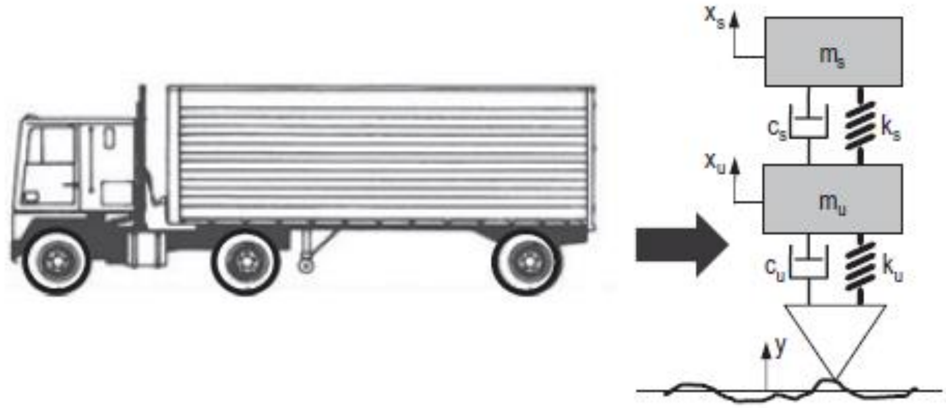

Figure 8. Schematic of two degrees of freedom quarter-car vehicle model (Rouillard, 2008)

4.3. Shock Modeling

The first step for making a reliable shock simulation is to understand the properties of the material of the solid subject of study, such as modulus of elasticity, density, temperature related constants and others that can influence the shock wave velocity (Žmindák & Pelagič, 2012). Focusing on paperboard, which is a common material used to pack products, these properties may vary according to their design as Park et al. (2012), Figure 9, and Patel et al. (1997) presented.

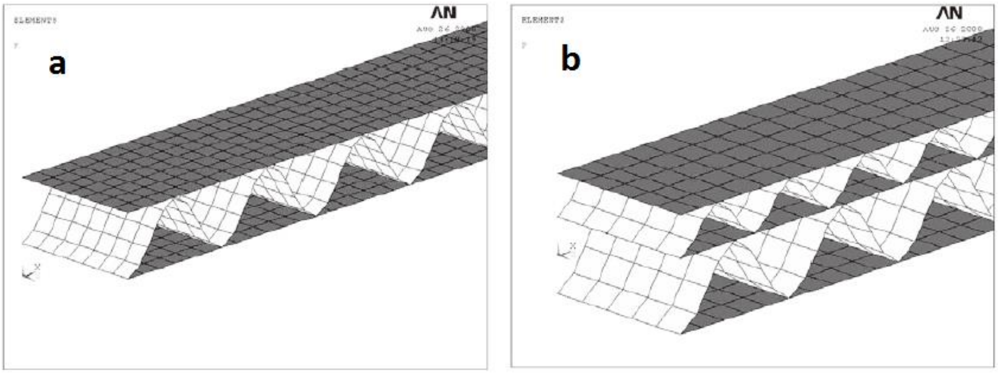

Figure 9. (a) Single-wave paperboard, (b) Double-wave paperboard (Park et al., 2012)

In another study (Nordstrand et al., 2003) the strength of a corrugated board container was analyzed with ANSYS software. The core of the corrugated board was assumed as homogeneous, the complete corrugated board was represented by a multi-ply eight-node isoparametric shell and a symmetry was assumed, being analyzed only a quarter of the box with the purpose to reduce computational time and make the simulation more viable. The finite element model was compared with experimental data and showed reliability for predicting the failure load of boxes. It is therefore of paramount importance to accurately define the material properties of the analyzed system submitted to shock if one desires to obtain a reliable numerical modeling once their characteristics highly influence their behavior against shock efforts. Knowing the material properties, the shock is obtained initially from the time-history vibration, which is described in terms of its inherent features of the shock, in the time domain, in the frequency domain or by a description of the shock in terms of the effect on structures when the shock acts as the excitation (Harris, 2002).

5. Conclusions

The present work summarized the three main causes of damaging palletized products during transport; sloshing, vibrations and shock, explaining the theoretical basis of each one, practical aspects of their occurrence and a brief state-of-the-art review on their study through numerical simulations.

Diverse factors cover the transport of merchandise and are crucial to determine their delivered conditions. The transport modal chosen is not always ideal due to the availability of infrastructure, and truck conveyance is undoubtedly the one that harms the load the most having in sight the inconstant accelerations, brakes, turnings, bumps and road vibrations. For this reason, packaging technologies had evolved significantly in the last decades with novel wrapping and cushioning materials to assure the integrity of the transported load. This evolution, as any in industry, is backed up by solid researches that not only evaluate damage mechanics on the go, but also foresee them aided by advanced computational tools and mathematical models.

The foment of studies in this area is essential to enhance and optimize current packaging materials and techniques, where the pallet must remain intact from its assembly to its delivery in order to meet the high-standard consumer's demands on the current competitive market. Thus, the development of current and new researches is extremely encouraged, given that a loss in efficiency to deliver good quality products to the customer's reach represents a direct or indirect financial impact for all stakeholders, where also the environment suffers from toxic emissions of poorly-efficient means of transportation and wasted merchandise.

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