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INDUSTRIAL PACKAGING: TECHNOLOGY, APPLICATIONS AND PRECAUTIONS IN THE CASE OF PALLETIZED PRODUCTS

Abstract: *The packaging sector is rapidly rising in the last years and it is continuously looking for new techniques for development and optimization. In this industrial sector the producer has the target to ensure a packaging able to contain the load within a certain volume and at the same time to protect it from the environmental effects. One of the most critical issues in this sector is related to handling and transport of the products, when they can experience disastrous consequences for their integrity. This fact has encouraged the producers to develop new techniques to investigate the environmental conditions and the level of stress acting on the products during transport and handling. Only in this way it is possible to look for new innovative solutions, more effective in the containment and protection of products. In this work we will focus on those aspects related to transport of palletized products, trying to provide a state of art of the solutions used for protecting goods.*

Keywords: *Packaging, Transport, Handling, Palletized Load; Integrity Protection*

1. Introduction

The globalization of the industrial marketsleads to a continuous increase in the trade flows. Every day large amounts of goods move along logistic chains and then along thousands of kilometers on the road around all the world.

Certainly, the producers are increasingly aware of the aspects related to the packaging of goods: a packaging, to be effective, must protect goods during handling and storage, moreover it must be as cheap as possible.

Most of products are positioned on a pallet and then they are stabilized through different techniques. The one that is rapidly rising is characterized by the application of polyethylene cold pressed film along the perimeter of the pallet, on several heights; this technique shows good stabilization properties and low operating costs. At the same time, it is not possible to say that the other solutions are losing pace.

On the contrary, it seems that all the different secondary packaging technologies are making their own spaces where they show some superiority in terms of performance.

The present work is focused on detailing several aspects related to the packaging and the transport of palletized products, trying to provide a state of art of the solutions used for protecting our goods during movements and storage. Furthermore, the attention is focused

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on the capacity to stabilize and contain during the most dangerous event for a palletized load: the transport.

2. Packaging features

A package is characterized by the use of a product, composed of any type of material, designated to contain and protect certain goods, from raw materials to finished products, to allow their handling and delivery to the consumer, and to assure their presentation.

The package must satisfy several requests, including goods protection, prevent theft, be cheap but constantly respect a good balance between performance and cost, both for the used material and the time employed in order to realize the packaging operation.

Moreover, from the ecological point of view, it is important that for packaging it will be used materials that can be easily recycled and in the least possible amount.

2.1. Standards

Technical information and scientific literature are quite large on the topic, permitting to achieve a valuable level of knowledge, both at the level of theory and practice.

As first, useful standards onthe experimental validation of packages safety and integrity can be considered (between the others), the *EUMOS 40509*, regarding a test method for evaluating the load unit rigidity, the *ASTM D5276* for measuring the effect of free fall of loaded containers and the *ASTM D4003* regarding the impact tests for shipping containers and systems.

Eachstandardis focused on a specific aspect that could emerge during the transport (as accidental falls or impacts), but misses to consider the ordinary conditions existingduringtransport (e.g. movements, vibrations).Other norms can be used to fill this gap, as the *ISO 2247*dealing with the vibration tests at fixed low frequency or the *ISTA 3B* and *3E* aiming at proposing generaltest procedures for simulating the protective performance.

2.2. Investigations

Also in terms of studies and research, a large availability of usefulinformation already exists, as summarized in *Fragassa et al, 2017*.

For instance, *Jarimpos et al, 2005*, measured and analyzed the vibration levels during truck transport and evaluated the level of damage reported by packaged tangerines. In *Zhou et al., 2007*the effect of transport vibration was investigated in the case of pears, not only focusing the attention on the damage mechanics, but also on the physiological responses of fruits.

Later, *Berardinelli et al., 2013*investigated the effects of these vibrations over fragile shell eggs by the definition of quality indices and their monitoring during the different phases of a transport.

Blumer and Guadagnini, 2011 highlight the transmissibility of shock waves caused by forklift truck handling to the palletized loads, while *Singh et al. 2015*focus the attention on the phase of transport by ULD dollies inside theair-cargo sorting hubs.

Other researchers focus the attention on the different geographic areas and means of transport. For instance, Borozc, together with his colleagues, propose a first investigation on the measure and analysis of vibration in rail transport in central Europe (*Borozc et al., 2015*), later extended to consider the LTL freight shipping between Central Europe and South Africa (*Borozc et al., 2016*).

In other parts of the world, similar investigations are presented by *Fei et al, 2008* for truck transport in Japan, by *Singh, et al., 2007* for truck and rail shipping in

India, by *Zhou et al., 2015* in China with the measure of vibration levels as a function of road conditions, truck speed and load levels; by *Rissi et al., 2008*, for truck transport in Brazil or, finally, by *Manuel et al, 2008*in Spain where a function of payload, suspension and speed was also developed.

2.3. Models

Several studies propose theoretical methods or numerical ones as a way to predict the effect of transport on goods with the scope to develop predictive models for a larger use.

Inside a theoretical approach, it is noteworthy the list of works proposed by *Wang Z.W., Wang J.* and their colleagues, from 2012 to 2016, with the scope to develop and apply an inverse theory for investigatingthe dynamic characteristics of product transport systems.

For instance, *Bernard et al., 2010*, presents a study on the dynamic behaviour of stacked units using a modal analysis, not very different respect to researches on stiffness optimization coming from other productive sectors (as in *Pavlovic et al., 2016*).

In these terms special attention is reserved in modelling the response of the basement respect to changesin materials or conditions. This is the case, for instance, of *Lu et al., 2014* and *2015*, for the corrugated paperboard.

Therefore, even if without the consideration that characterized other processing industries (e.g. machining, as in *Fragassa, 2017*), it is evident how the relevance of the basement is emerging in every investigation dealing with the overall stability of the pallet.

Adding,also the potentialities of the Expert and Intelligent Systems are recently called for help in these numerical approaches.

It is the case of *Lepine et al. 2016*who propose to use theMachine Learning to detect shocks in road vehicle vibration signals.

But, as expressed by *Bernard et al., 2011*, it remains the necessity to match simulations with tests and measures. It is clear in *Ge, 2000* with the development of a new model for acceleratingthe vibration tests or in *Zhong et al, 2013* where improvements in the most conventionalmodels used for performing drop tests on packages are proposed.

This validation by tests also depends by the undefined factors that can be encountered in modelling the reality by numbers. *Lak et al, 2011*, for instance, evaluate the change ofspectra of vibrations in accordance with the road unevenness and the road traffic.

The same interest is in *Bruscella, 1997*,with aninvestigation on the influenceof the road roughness respect to the(spectral) measure of the package performance.

Additional aspects, not directly related to the vibration or to the transfers have been considered in other studies, as in *E Yui-Ping and Wang, 2010* where the effect of humidity on absorption properties of packaging materials are evaluated.

The general scope is to develop materials and design solutions able to reduce the risk of damages, as imagined by *Martins and Dell*,in *2008* or by *Zhang and al.* in *2016*.

On the contrary, the current research aims at detailing the technical state of art of the packaging technology after several decades of changes and improvements.

3. Packaging types

Packaging can be distinguished in three different types or functional categories: primary packaging, secondary packaging and tertiary packaging.

3.1. Primary packaging

Primary packaging, or for the sale, is a packaging conceived to constitute, in the store, the final unit for the user or for the consumer.

Some examples are one bottle, a box of tuna, a case for CD, a pack of cigarettes.

So, in case of consumer goods, primary packaging represents the selling unit destined to the final consumer.

It must fulfil the following requirements:

- Ensure product storage;
- Preserve product shape;
- Guarantee an attractive design.

3.2. Secondary packaging

Secondary packaging, or multiple packaging, is a packaging conceived in order to constitute, in the store, the grouping of a certain number of selling units, regardless of the fact that it will be sold as such to the final user or to the consumer, or that it will be used only to facilitate the shelf replenishment in the store.Some examples can be a confection that contains more bottles (bundle), a confection of three boxes of tuna, a confection of ten cases for CD, a carton of cigarettes.

So, in the case of consumer goods, secondary packaging can constitute both the selling unit destined to the final consumer and retailer.

Some requirements it mustfulfill are:

- Allow internal and external handling;
- Have a shape and a design suitable for exposure.

3.3. Tertiary packaging

Tertiary packaging, or for the transport, is conceived to facilitate handling and transport of a certain number of selling units or multiple packaging, preserving goods from damage related to transport.

Tertiary packages can be a pallet of confections of boxes or the same box containing confections.

In the case of consumer goods tertiary packaging is reserved to the utilization internal to supply chain and, except in rare cases, it will not arrive to the final user.

The characteristics of the tertiary packaging must be:

- Allow internal and external handling;
- Ensure protection from weathering;
- Ensure protection from tampering and theft.

The materials used for packaging can be different, for example paper, cardboard, plastic but it can be used also glass, wood, metal and other materials.

Now we examine in depth the techniques used for the realization of packaging for palletized products (so related to tertiary packaging) and the plastic materials used; in particular we will see the technique used to wrap the load with stretch film, the technology used by the machines produced by Robopac Sistemi.

4. Packaging techniques for palettized products

The accommodation of the load is performed in order to prevent potential instabilities in storage and handling phases; indeed shocks, sudden movements and dangerous tilts can compromise the integrity of the load.

Nowadays, in almost all cases, the product is placed on several planes on a pallet, i.e. a wood structure specific for the stabilization of the palletized product. This stabilization task can be carried out in several ways, depending on the type of product and situation.

4.1. Shrinkable film

The packaging performed with shrinkable film is characterized by the wrapping of the load with a cap of plastic material film, with olefinic base, with different thicknesses from 50 to 150 micron. The material is firstly subjected to a heating phase, then to a cooling phase, it withdraws in length and width, joining to the load that is wrapped.

The main features of this material are:

- Good stability conferred to the load;
- Good adhesion of the film to the products;
- Excellent protection from weathering;
- Good protection from theft and tampering;
- Good capacity to transmit promotional messages by means of printed films;
- High energy costs due to shrinking;
- High consumption of material;
- High storage costs, above all in case of load of variables dimensions;
- Issues related to the transit of the products through the retraction oven (condensation, surface warming, etc).

This kind of technique finds greater application in the industrial sectors of chemistry, fertilizers, brick, glassworks and in general where it is specifically requested a water-proof protection on the five sides of the load with external storage.

4.2. Taping

The use of adhesive tapes realized mainly in plastic material (PVC and PP), for the sealing of cardboard boxes (taping) has almost completely replaced the use of hot glues and scratch of various shapes and dimensions.

The advantages of the use of adhesive tape for the fastening of cardboard boxes are remarkable and they justify the almost exclusive use of this technology on the filling cardboard end line.

The adhesive tape guarantees inviolability to the box at much lower cost than strapping and without the typical management and maintenance issues of the hot glues.

The machines for the placement of the tape are simple, low cost, reliable and, in general, they need very little maintenance also for high production rates machines.

The tape, unlike strapping or other systems, does not ruin boxes with cuts or engravings, it can be cut effortless and it allows a good customization of the package.

4.3. Strapping

Strapping is the most mature technique and it consists in tightening the load through a strap of plastic material (polyethylene, polyester) of a width variable between 8 and 15 mm or through a metal strap.

It has the following features:

- High tighten load can cause an engraving in the packaged load;
- No protection from weathering;
- No protection from theft and tampering;
- Reduced stabilization effect in case of removal of one or more units;
- High cost of the packaging;
- The machines used to apply strapping are very complex.

Strapping find its application in the heavy industrial sectors (steelworks, foundries, etc), in brick and paper sectors.

4.4. Stretch film

The stabilization of palletized load is obtained through the application of one or more layers of plastic adhesive material on the same load.

This material is normally composed of a film in extensible linear polyethylene (LLDPE), it shows up as a transparent film and it is suitably stretch through cold mechanical elongation before it is placed on the load.

This technique is one of the most recent and it was developed during 70's with remarkable growth rates. Thanks to the features of flexibility and ease of use of the wrapping machines, to the low energetic exercise costs and low packaging material costs, wrapping with extensible film has replaced in several applications strapping and shrinking.

The main features of this technique are:

- Good load stabilization;
- Good adhesion of the film to the product;
- Good protection from theft and tampering;
- Good protection from weathering if during wrapping operation it is added a sheet roofing on the top of the palletized load.

5. Wrapping process by means of stretch film

The main purpose of the end-line packaging is to stabilize a palletized load by applying on it one or more layers of adhesive plastic material.

This material shows up as transparent film and it is suitably stretch by means of a cold mechanical elongation before it is applied on the load. Thanks to the elastic memory of the material, the film exerts compression forces that can assure a good stabilization of the load.

In order to guarantee that the film is correctly applied (efficient and effective) there are some conditions that need to be satisfied:

- It must be suitably elongated by stretching;
- It must be applied to the load under applied tension;
- It must suit perfectly to the load conformation by means of the effects of elastic recovery;
- It must not deform the load during or after the wrapping.

The film used in wrapping processes is realized in polyethylene, a polymer obtained from the polymerization of the ethylene monomer; it belongs to the category of thermoplastic materials, soft and flexible, and it is semi-crystalline.

Figure 1 Composition of ethylene monomer (left) and polyethylene polymer (right)

The ethylene has two carbon atoms and four hydrogen atoms, the repeated structure of the polyethylene has the same composition.

The molecular weight, the crystallinity, the structure and, accordingly, the properties depend on the different production processes, that are characterized by exercise pressure very different and that have as results the different types of this plastic. The main features of the polyethylene, that are important for its huge diffusion, are:

- Low cost;
- Good workability;
- Excellent thermal insulation properties;
- Good transparency of thin film;
- Absence of smell or toxicity;
- Permeability to the vapor quite enough for several applications of farming, building and packaging type.

His main limitations are:

- Low softening temperature;
- Absence of stiffness;
- Modest resistance to scratch;
- Opacity in the material if it has

considerable thickness.

These limitations have hindered the use of polyethylene in several sectors, but certainly not in packaging, where these limitations do not lead to problems while the advantages stand out much more sharply.

Now we will briefly focus on the mechanical behavior of the material. As we can see in the figure 1.2 there are three different areas related to the behavior of the material.

In the first area (area A) with an applied force to the material we can obtain a proportional deformation (elongation). In this area the polymer has an elastic behavior, i.e. if the application of the force stops the material will return to the initial dimension.

When the yield point is reached, we will pass to area B, in this area it can be obtained a remarkable elongation of the film with an increase of force almost negligible.

In this area the film shows a plastic behavior and the recovery of the original shape would be only partial, if the load will be released.

Indeed, if we stop in point 2 of the curve and we release the force applied on the film, its recovery would not happen on the same elongation curve, but along the curve that connects point 2 to point 1', that it is more inclined than elongation curve in the area A.

This feature results in the fact that if we now would stretch again the film of a certain value, we will have to apply a higher force than the one applied firstly in area A of the graph.

This behavior is due to the properties that the material acquires as a result of the plastic deformation occurred after the yield limit.

The last area (area C) includes that part of the curve where the polymeric chains that compose the film arrive at break due to a further increase of the applied load and to the deformation.

Finally, we can say that to obtain the best economic performance we have to stretch the film until its possibility, i.e. stopping before break area (area C). At the same time in this zone the film has also the best features to contain the load on the pallet.

Indeed, the containment force exercised on the load to be wrapped is maximized.

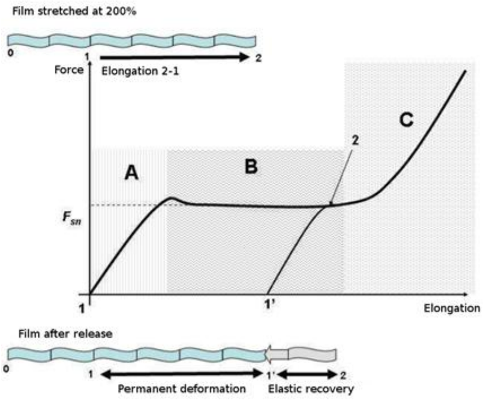

Figure 2. Force-elongation graph for a polyethylene specimen

6. Types and characteristics of wrapping

The load, during the handling along logistic chain, risks to be damaged because of shocks and abrupt accelerations: for this reason, it is important to realize a packaging that minimize these risks and at the same time economic losses.

The packaging realization of a palletized load is performed applying along the perimeter of the pallet, on several heights, many layers of polyethylene film properly cold stretched.

The machines that can accomplish this task are called wrapping machines.They can be divided into two groups, according to the operating principle:

6.1. First type machines

The wrapping occurs when the pallet rotates with respect to the spool holder carriage; the rotation occurs by means of a motorized rotating table.

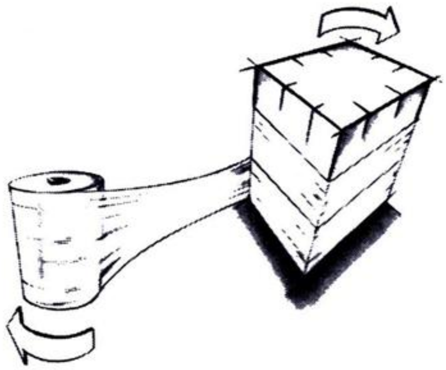

Figure 3. Conceptual framework of first type machine

6.2. Second type machines

A spool holder carriage in this case is rotating around a center, where the pallet is placed, while some rollers provides the film unwinding.

According to the mechanism used to sustain the spool holder carriage the machines are divided in “ring” or “arm” machines.

The stretch effect suffered by the film before the application on the load, or pre-stretch, is used to reduce the thickness and so the weight of the material, and it confers to the film mechanical features such as it is most suitable to sustain the forces acting on the pallet. (as shown in *Singh*, *Blumer et al, 2015*)

Indeed, after plastic deformation, the stabilization capacity of the film gets better. If the palletized load moves, stretching the film, it reacts increasing compacting force to go back to its initial condition; this stabilizing effect is the more amplified the greater was the plastic deformation before wrapping.

The compacting force is a parameter related to the wrapping force: according to the load type placed on the pallet the operator can want a greater or a lower force (low for soft and weak loads, high for rigid and heavy loads).

It is also important the aspect related to the saving of material used depending on the stretching: the cost of the polyethylene film is not negligible, particularly for the companies that move huge volumes of goods of low value. In parallel the quantity of trash produced is reduced.

It is evident how stretching the film until its possibility, i.e. stopping only before its break zone, it is possible to obtain the best economic performance and the best stabilizing effectiveness.

During stretching process, we need to consider also the phenomenon of the film band reduction in the direction orthogonal to the feed one; indeed, if we obtain a closer band, we have to carry out more revolutions to wrap the load along his entire height.

The most simple and economic machines allow to stretch the film not much and with a relevant reduction of the band height, while the most performant and expensive allow to stretch the film a lot (until 400%, so linearly from one meter of film five meters are obtained) ensuring at the same time a negligible band height reduction.

7. Spool holder carriages

Now we focus on the most important component of the wrapping machines, i.e. the spool holder carriage, that has the task to realize the stretch of the extensible film.

It is very important to distinguish between the notions of stretch and pre-stretch.

In the first case we talk about a process, that can be defined passive, where the elongation of the film is produced only by the force exercised from the relative rotation of the pallet that has to be wrapped with respect to the spool holder carriage; this rotation is countered from a braking device.

When we talk about pre-stretch the elongation of the film is generally realized independently of pallet movement, with two rollers that rotate at different velocities. These pre-stretch rollers allow a precise control of the pre-stretch phase and, if motorized, they can allow the regulation of the wrapping force until very low values. The result is a better control of the extension process and a better use of the film.

7.1. Carriages without pre-stretch option

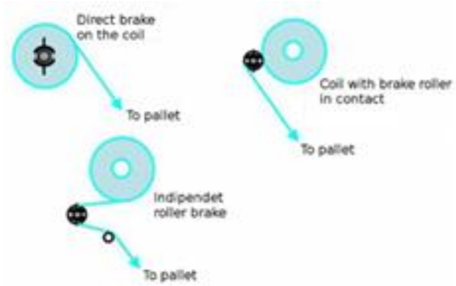

Figure 4. Operating schemes of carriages without pre-stretch option

In this type of carriages, the film is pulled by the pallet in rotation; there is a braking device on the carriage in opposition to the force and this system causes the stretch of the film.

In the conventional system the film spool is slowed down by a magnetic or electromagnetic brake; otherwise the braking effect can be obtained by means of a contact with another roller that is controlled by a magnetic or electromagnetic brake.

The stretch force applied to the film is equal to the wrapping force on the pallet; this is a big constraint that limits the flexibility of the machines provided with this simple carriage configuration, because there is direct dependence between the elongation of the film and the needs of managing the wrapping forces on the load.

This system is characterized by the following features:

- The stretch level varies depending on the value of the braking;
- The maximum stretch efficiency is around 50-60% because of the relevant decrease of the film band height (neck down);
- The stabilization effectiveness of the film on the load is relatively low, because the film is not plastic deformed in a consistent manner.

7.2. Mechanical pre-stretch carriage without motor

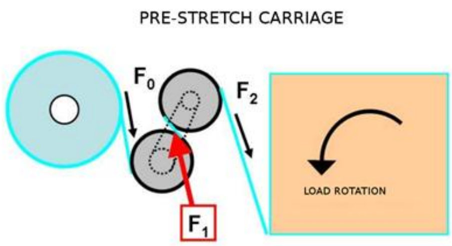

Figure 5. Operating scheme of a pre-stretch carriage without motor

Also, in this case the film is pulled from the pallet in rotation; but, with this configuration, it can be obtained a pre-stretch between two rollers that are connected by a gear or a belt that make them rotate at different speeds.

The simplicity of this solution resides in the fact that it does not require any electromechanical component, because the pre-stretch rollers are moved by the contact friction of the film.

The wrapping force F_2 is lower than the pre-stretch force F_1 that is exercised between the rollers: so, it is allowed to wrap the palletized load with more elongated film (until a maximum of 100%) with the same wrapping force of the system without pre-stretch.

The wrapping force F_2 increases when the pre-stretch force F_1 increases, that is also related to the value of pre-stretch ratio; to change this value it is necessary to substitute the couple of the toothed wheels or pulleys that connect the two rollers.

The unwinding force of the spool F_0 is not zero, but it is considered zero because it is negligible with respect to the other forces involved in the system.

This system is characterized by the following features:

- Partial isolation of pre-stretch process, also if the secondary stretch, due to the pallet force, is however present;
- No direct control on the wrapping force, this fact limits the quantity of obtainable pre-stretch;
- The elongation levels of film are higher than those obtained with carriage without pre-stretch systems;
- The reduction of film band height is lower than the case of simple stretch.

7.3. Mechanical pre-stretch carriage with one motor

The reference configuration scheme is equal to the previous one: the difference is the introduction of a motor on the pre-stretch system in order to make independent the pre-stretch process from the rotation of the load.

In this way the pre-stretch force F_1 is no more correlated to the wrapping force F_2 (as well stretch force), and this fact allows to reach high level of pre-stretch without increasing the wrapping force.

This force can be very low, with values close to zero when wrapping needs require this configuration.

The pre-stretch ratio can vary both modifying the toothed wheels (or the pulleys) that connect the two rollers and acting, on the machines that can have this feature, on an electromagnetic friction that varies continuously the ratio.

Obviously this second configuration gets better in terms of machine flexibility, but it is characterized by a higher complexity and cost.

7.4. Mechanical pre-stretch carriage with two motor

A further development of the pre-stretch carriage with only one motor is the carriage with double motorization; in this case the two rollers are motorized individually, there is no more a rigid connection between them, and their rotation velocities become completely independent.

This fact allows to manage continuously the pre-stretch ratio, with the maximum flexibility and precision; every variation of the working parameters can be done through on-board control panel acting on the pre-stretch motor drives, without stopping the machines.

These carriages guarantee the maximum performance in terms of pre-stretch ratio achievable, flexibility and precision of the wrapping process.

7.5. Compensation of load edges

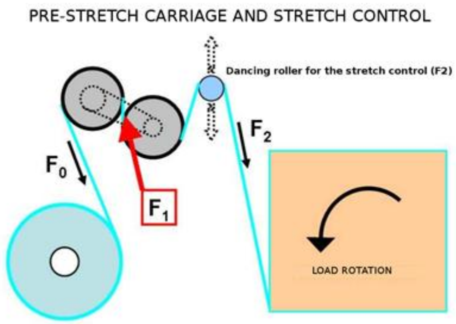

Figure 6. Pre-stretch carriage with stretch control system

If the pallet would be circular there will not be problems during wrapping process, due to absence of edges; the problem arises when, in general, the loads to be wrapped have a rectangular or square plant.

When the palletized load rotates, every time that the film must cover the edge the system receives a higher request of film. If the film distribution system (carriage + spool) can't unwind more film when it meets an edge, higher forces appear on the load, in correspondence of this edge; in order to solve this problem several systems were put in place. The most advanced are those related to the use of a mechanical dancing roller or an electronic load cell. These techniques allow a good control of the pre-stretch ratio and they are coupled with a control system on the wrapping force on the pallet.

The mechanical dancing roller is a tilting crowds roller interposed between pre-stretch fast roller and the pallet; the variation of the wrapping tension of the film due to the presence of edges leads to the movement of the dancing roller. A sensor notices this movement and, depending on data acquired, acts on the motor (or on the motors) increasing or decreasing the rotation velocity of pre-stretch rollers (maintaining however the same constant ratio).

In this way it is unwound respectively a higher or lower quantity of film.

So, by means of the dancing roller, the wrapping tension of the film can be kept constant, also in correspondence of load discontinuities (load edges).

With the aim at improving the overall quality of packaging, but also the whole industrial process (similarly to *Lukic et al., 2018*), further solutions can be imagined in the near future. It is the case, for instance, of the use of magnetorhological fluid devices for a dynamic control of the wrapping tension (as proposed in Fragassa et al, 2016)

8. Conclusion and further steps

This paper represents a practical state of arts regarding the main solutionsfor packing, transporting and storing goods by palettized products. The study, of course, does not claim to be complete, but is proposed as a basis for subsequent developments.

According to our plan of investigation, the next step is focused on the design of a measurement system that can characterize motion and environmental data of a palletized load during its entire route, from handling on the forklift to the truck transport.

This new activity aims at analyzing, by means of a specific test bench, the conditions of loads and performance of a palletized products in the case of different wrapping patterns and different characteristics related to transport.

With this scope,it is necessary to develop an entire test bench for the experimental test, made by vibrational and environmental sensors, signal filters and controllers, transmitting devices and so on. Depside of the technical difficulty, thanks to this test bench, it will be possible to reach afull characterization of the palletized load behavior in real conditions by means of the data acquired from the pallet.

This registration should lead the company to be more aware about palletized load behavior during handling and should allow the replication of these behaviors in laboratory test through vibrating platform.

As final goal, it will be to give the possibility to act adequately in the study of the wrapping pattern in the way to guarantee stability and robustness to the load respect to thedifferentconditions of transport.

Thus, the experimental analysis will becomea fundament in this kind of optimisation, indeed it was demonstrated that the stresses imposed to the load during standard test are lower than those suffered during a real transport. So, the only way to give to the customer a product assuring its integrity during transport is to simulate the transport itself as accurately as possible. The goal of our next work is to provide to the company a measurement system whereby has the possibility to carry out these simulations through a vibrating platform.

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