Aspects of Safety in the Stretching of Plastic Film During Greenhouse Covering

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Abstracts

The "Mediterranean greenhouse" is widely used for food and ornamental crops. In south-eastern Sicily alone it covers 7000 ha -7500 ha, for 13200 ULA (working days per years) and with a gross saleable production of € 255˙000˙000. Over the course of time the wood or cement supporting structure has been replaced with steel structures. In all cases the cover consists of polyethylene film (PE, PVC, EVA, and so on) and is replaced annually or at most every two years. The positioning of the film on the greenhouse frame represents an accident risk, with falls from a height, and the stretching of the film may provoke even fatal accidents. The equipment used contributes to such accidents. The objective of this work is to identify the cause of accidents occurring during the stretching of the plastic film and to propose solutions. To measure the force involved during tightening, a torsiometer was used. The characteristics of this were established through preliminary trials and a procedure was set up for its correct use. An analytical model was prepared to verify the forces in play. The results show the significance of the forces used during stretching and indicate the danger involved in the operations. The research shows the need to set out guide lines, scrupulously train the operators, re-examine the devices in place in greenhouse structures to hold the film during stretching as well as the tools used by operators, as impact of these with parts of the body can have fatal consequences.

Keywords: torsiometer, covering, safety procedure, plastic film

Introduction

Positioning plastic film over the structures of the "mediterranean greenhouse" may provoke high number of the accidents at workers involved in (Miranda and Martinez, 2005).
Preliminary investigations conducted by the Authors in the south-east of Sicily confirm the high risk of this activity, but underestimated, because accidents are not always reported.
Some researchers propose a system that allows the coverage of the structure, working from the ground and then lift the whole covered structure so until final height. Where applicable, the system shows a drastic reduction in accidents during the coverage phase of the structures (Carreno, 2009). According to the author, the working hours dedicated to these tasks and therefore the risk exposure are reduced as well.
Besides being subjected to the typical risks of working at heights, the workers employed for covering activities use home-made and often very rudimentary equipment, which are a source of danger or even death.
The target of this research is to experimentally measure the magnitude of the forces involved during the stretching of the plastic film as roof of the greenhouse, to interpret and suggest a model confirming the experimental results, and to detect and evaluate the procedures and the tools used to achieve useful information for risk reduction.

Materials and Methods

Materials

Greenhouses. Greenhouses where the tests were performed (referred in this work with the first five letters of the alphabet) are of tunnel type with multiple spans and a symmetric curved roof; they are the most common greenhouses used in south-east of Sicily.
They have lateral windows, a main structure (carrier) and a secondary (for connection) made by galvanized steel and a roof made in plastic film (see Table 1).

Rif.	Width [m]	Span [n.]	Depth [m]	Eaves height [m]	Ridge height [m]	Surface [m^2]
A	56	7	19	2.70	4.30	1064
B	48	6	19	2.70	4.30	912
C	56	7	25	2.70	4.30	1400
D	56	7	30	2.70	4.30	1680
E	56	7	32	2.70	4.30	1792

Tab 1 - The greenhouses

The used plastic film (EN 13206, class A) is the ADDITIVATO®, with long-term characteristics, nominal thickness of 0.15 mm and coil width of 9.20 m. It is usually replaced every two years.

The torque transducer. In order to measure the torque required to tighten the film on the rod, it was used a static torque TRS (AEP transducers) compliant to the standards EN 61326-1 and EN 61010-1 (2001) with which it is possible to measure torque ratings from 0.5 to 1000 Nm (Fig. 1).
It is equipped with a digital torque DTR (digital torque indicator), with input for strain gauge torque transducers. Thanks to the peak function, the indicator provides:

- a positive value (clockwise peak torque)
- a negative value (counterclockwise peak torque)

Fig. 1 – The torsiometer and the digital torque indicator

Methodology

In all tests it was measured the heights of the wrapping groups (terminal device and ending part of the rod), with respect to the floor, as these involve different postures and procedural approaches of the operators during the installation of the plastic film (e.g. use of ladders, more or less raised arms, etc.).

In each test, the torque transducer was interposed between the wrapping groups and the hollow rod that protrudes from the "rosette" (fig. 2). Then the lever is connected to the transducer in order to apply a force by hand with the purpose of wrapping the film around the bar itself (Fig. 3).

Through the torque transducer, which was reset for each reading, the measurements were performed during the wrapping phase.

As the display of the DTR allows the reading of the torque in real time, in case of abnormal records it was possible to make an immediate investigation by questioning operators, exchanging point of views with members of the research group, examining the results on the precise moment or later from the movie of the operations.

Fig. 2 - The wrapping groups: the "rosetta" and its 8 curved points, the hollow end of the rod, the blocking systems with the hinged mobile tooth; the whole rod is not visible here

Fig. 3 - The long lever used for stretching the film, with the pawl,
the torsiometer and the square key to insert in the hollow end of the rod

Results

Work organization. The step of fixing the plastic film necessary to cover the greenhouse was performed by a team of 7-8 workers, two of whom work on the ground and operate for the withdrawal of the film from the reel, provide for the cutting of the film and moving the tractor that carry the film reel; four of these provide arranging the film on the coverage moving at height, two ensure the clamping of the film to the greenhouse structure by placing some clips and to a first tightening of the film, by using a pawl.

The two operators, located at each end of the span, act in unison, each with its own wrench, on a "wrapping group". The final tensioning of the film takes place during the hottest hours of the day to avoid that low temperature early in the morning may provoke breaks in the film or incomplete stretching.

Wrapping groups. The "wrapping groups" are located both front and side of the greenhouse. Each group consists of a rod made in cold galvanized steel and a device ("wrapper") located at each end of the rod. The rod is at the height of 2.7 m with respect to the floor, cross - section square (30 x 30 mm, thickness 2 mm) and some tens of meters long (max 50 m).

The 'wrapper' and the wrench used to wrap the film are the heart of the system. The wrapper group allows the insertion of a wrench for rotating the rod and it is equipped with a device that allow to rotate the wrench without unplugging it.

The device consists of a toothed wheel called "rosette" made of cold galvanized steel 6 mm thick. Both terminal parts of the rod protruded from its own rosette and here it is possible to insert the wrench. Each rosette has 8 curved points with special shape in order to allow the smooth functioning of the locking device. This consists of a mobile tooth hinged at one extremity and able to prevent the opposite rotation when the wrench is disconnected or when the shaft of the wrench (that bring a pawl at its extremity) is rotating between a tightening and the successive one (the device should act as a rudimentary free wheel of a normal bicycle).

The wrench (equipped or not with a pawl) used to wrap the plastic film on the rod is usually self-built by operators or, more rarely, by manufacturing companies of materials for greenhouses. In the considered case study it was represented by a steel lever 1.08 m long. At one end of this lever a pawl with a male spanner (25 mm x 25 mm) is mounted; the spanner is suitable to be inserted inside the hollow terminal of the rod, nearby the rosette.

The torque values detected. In the table (Tab. 2) it is shown for each greenhouse the peak torque values measured by the electronic device:

Rif.	Rod lenght [m]	Minimum torque value [N·m]	Maximum torque value [N·m]	Average torque value [N·m]	Standard deviation
A	19	252	347	313	30.20
B	19	249	388	318	41.56
C	25	354	526	450	56.58
D	30	340	572	448	64.28
E	32	414	498	458	25.60

Tab. 2 – The peak torque measured values

It is possible to observe as the torque values in question have a range from a minimum of 249 Nm to a maximum of 572 Nm. The most common values of torque are those between 300 ÷ 350 Nm and between 400 ÷ 500 Nm (Fig. 4).

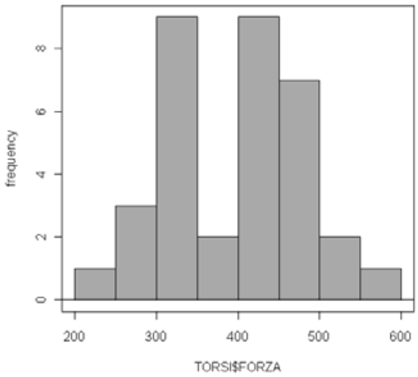


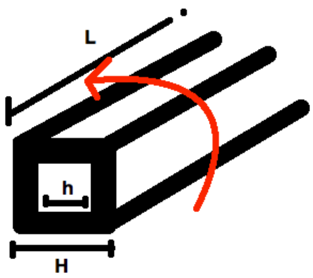
Fig. 4 - Distribution of the frequency

Analyzing the torque peak data, made separately for each greenhouse, is pointed out that in some greenhouses were reported values of 15-20% more than the average values.
These values, which can be defined as "exceptional", were measured in 4 of the 35 examined cases. In particular, a case was registered in the greenhouse B (peaks of 388 N* m, above the average of 22%), two in the greenhouse C (peaks of 526 and 517 N* m above its average of 17 and 16%), one in the greenhouse in D (peak of 572 N* m above the average 25%). The survey has indicated the cause in the lack of synchronism between the operators during the tightening procedure.
The analytical model and the forces at play. Assuming that the rod and plastic film are under elastic behaviour (the rod and the film are not under a strain over their elastic limit), the energy supplied by the operator to tighten the film is stored by the system and therefore the torque released by the rod in the following instant the release of the locking device could be assumed equal to that exerted to tighten the plastic film.
If the locking system doesn't work properly, as sometimes happens, at the time of release the system would give off a maximum speed; part of the energy would be after dissipated in static and viscous friction: these components can be considered negligible compared to the involved torque values.
It is possible to highlight two different cases:

1) The movement of the two operators is fully synchronous (ideal case). In this case there will not be a twist of the metal rod but only traction of the plastic film.
2) The movement of the two operators is asynchronous or even one of the ending parts of the rod is locked. The last circumstance occurs when an operator acting alone and acts alternately at either end of the rod. In this case there will be both: the twist of the metal rod and the traction of the plastic film.

The system can therefore be modelled as consisting of two springs:

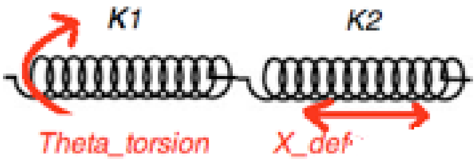
- A torsion spring represented by the rod with the following features:



H=30 mm; h= 26mm; L= 25 m

- A linear spring represented by the plastic film that gradually envelops the rod

Summing:



*F=K1*Theta_torsion+ K2*Xdef*

Where:

- K1: spring constant of the metal rod
- K2: spring constant of the plastic film

Since it is not easy to calculate the coefficient of elasticity for the two different materials, it was carried out considering:

- the torsion elasticity modulus (known for the steel rod and independent from the geometry)
- the stress arising from the traction of the plastic film, needed to tighten itself.

In the case of the square hollow rod having the characteristics listed above, the torque will be:

$$Mt = \Theta * Jp * G / L$$

Where:

- Θ is the twist angle in radians
- Jp is the polar inertia moment of the section;
- G is the torsion elasticity modulus (in the case of steel is a known quantity equal to 27 GPa = 27 N / m ^ 2)
- L is the lenght of the rod (L = 47 m)

To calculate the polar inertia moment it was used the following equation:

$$Jp = 2*J = (H^4 - h^4)/6$$

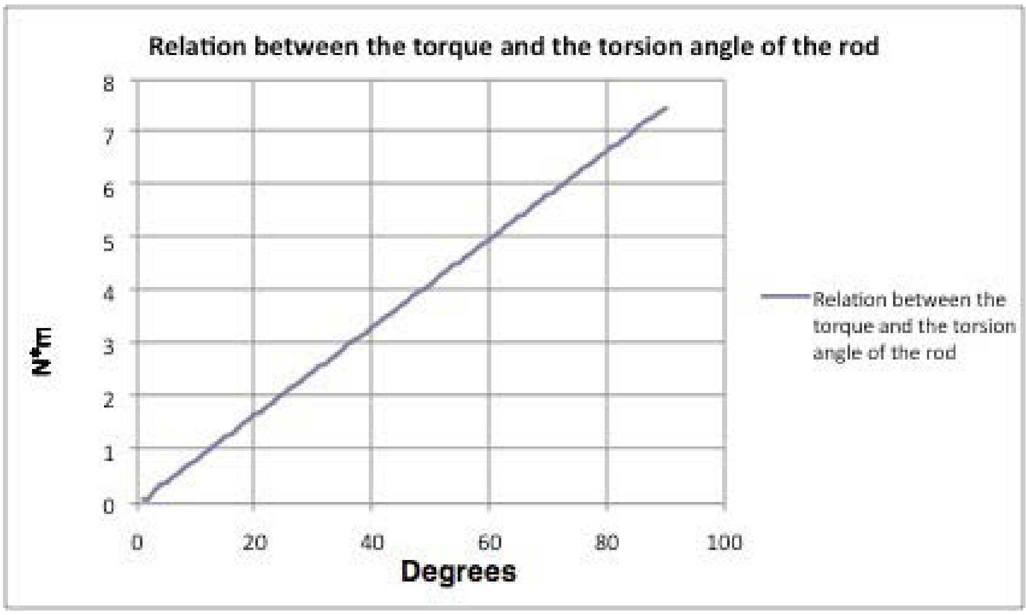


Fig. 5

Increasing the twist angle (generated by the asynchronous movement of the two operators or by the fact that one end is locked) will increase the torque value and then the energy returned from the system (Fig. 5).
For example, when the torsion angle is 10° the torque would result about 1 N * m (this corresponds to apply a force of ≅ 66 N on one side of the lever).
The following expression is useful to calculate the torque of the plastic film

$$Mt = F_{traz} * r$$

Where F_{traz} is obtained from: $F_{traz} /A = \sigma$.
With:

- F_{traz}: the traction strenght exerted in the plastic film from the operator that wrap itself.
- A: surface in wich it is exercised F_{traz} (equivalent to the section of plastic film: thickness * length).
- σ is defined as the effort exerted on the plastic film and it is measured in pascal.
- r: distance between the point where the traction is exercised and the axis of rotation (0.015 m).

From the mechanical parameters of the material used it is possible to know the breaking strength applied on the film (such as the thermal films AGRILUX that have an breaking strength ≥ 18 kN / m ^ 2).
Well below this value, the behaviour of the film is plastic and it is possible to calculate the torque generated:

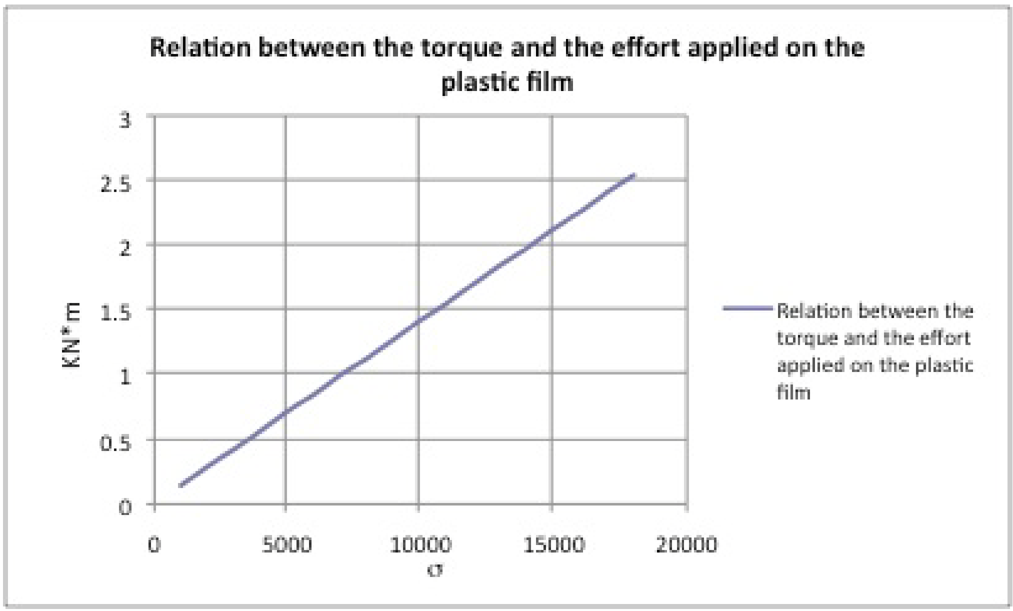


Fig. 6

Increasing the effort applied on the plastic film (18000 is the breaking strength) will increase the maximum torque exerted by the same (order of kN * m) (Fig. 6).
Analyzing the results, the predominant component in terms of resultant torque is generated by the plastic film.
The sum of the two components (rod and film) shows how under certain conditions the resulting torque is comparable with that measured experimentally (≅ 500 Nm).

Conclusions and prospects
The "wrapping group" (terminal device and ending part of the rod) is the heart of the system under review, with the tool (wrench) and the procedures used.
The rough construction of the group and of the wrench, and the improvised nature of the adopted procedure makes very difficult to adopt safety standards and all together they help to explain the frequency of accidents during the plastic film tightening phase; furthermore, the magnitude of forces involved, that the research allowed to quantify, justifies the severity of the injuries.
Both the rosette and the lock system should be redesigned more appropriately, the materials should be chosen with a greater care, the construction methods (stamping or cutting) revised.
The procedures, often incorrect, give rise to serious and even lethal risks, especially when the head of the operators (helmet is often not used) may be affected by the lever used for tightening the plastic film when, due to an accident, the operator lose the grip and consequently the control on the lever.
Maximum attention should be placed on the staff training and on the provision of appropriate PPE (Personal Protection Equipment).
The proposed analytical model, finally, gave results comparable with those observed and appears to correctly represent the types and the intensity of the forces involved experimentally measured. A further effort should be direct towards a complete verification of the possibility of pulling the plastic film using pairs of compact electric actuators, with low voltage and electronic control.