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RESEARCH ARTICLE

Post-Wrapping Behavior of High-Performance Stretch Film

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ABSTRACT

Compressive force is the energy a stretch film exerts onto the corners of a unit load of product, this paper analyzes the effects of compressive force overtime after application to a unit load. Previous research has shown how storage conditions, pallet configurations, and storage duration affect the performance of various packaging materials, however, there is a lack of this type of study relating to stretch film and load unitization. This paper looks at trends in compressive force depending on whether a film is applied with negative or positive secondary stretch. When a load is stretch wrapped with negative secondary stretch, meaning more feet of film is supplied than there is load perimeter then there is low compressive force on the corners of the load. Conversely, positive secondary stretch is when there is less film footage than there is perimeter of the load, so the film has to react and elongate in between the pre-stretch carriage and the load, applying greater compressive force at the corners. This study examined the effects of compressive force overtime using high-performance grades of both cast and blown stretch film. It was observed that the changes in compressive force varied depending on whether the film is applied to a load with positive or negative secondary stretch. A film application with positive secondary stretch will decrease in compressive force, while negative secondary stretch will increase slightly over time.

KEY WORDS

Stretch Film, Unit Load, Compressive Force, Secondary Stretch

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INTRODUCTION

Even in today's fast paced supply chains, pallet loads can still be warehoused for an extended period of time after production and before delivery to distribution centers or other nodes where they are broken down for consumers. In typical warehouse operations, packaged products are unitized together by stretch film and stored prior to transport. Warehousing and storage times can vary from hours to several months depending on the product and its intended application [1]. As a result, it is imperative to understand factors affecting a unit load during storage so it can safely survive shipment from the warehouse to the distribution center. Research has shown how storage conditions, duration of storage, and pallet configurations affect the performance of the packaging materials, most notably corrugated fiberboard. These factors have been well documented and are routinely used by packaging engineers during the design of the unit load system [2 and 3]. An area lacking in the research and literature are the effects of these parameters on stretch film, which unitizes the individual packages throughout the supply chain.

Broadly speaking, there are two types of stretch film produced and used within the packaging industry to secure loads for transport. These two categories are hand and machine films. These films are produced by a blown or cast extrusion process, with cast film accounting for the majority of machine film used in the transport packaging market [4]. Table 1 displays different stretch film attributes comparing film produced through these two processes.

Each type of stretch film provides different mechanical properties based upon on the film structure, manufacturing process. The selection of films varies based upon the application. These films should not only be selected based on the material properties, but also based on anticipated warehousing and shipping environments [5].

Regardless of film type, there are two different methods of stretch executed by stretch wrapping equipment: primary and secondary stretch. Primary stretch is executed within the carriage and commonly referred to as pre-stretch. Secondary stretch occurs between the carriage and the unit load as a function of film tension.

Primary Stretch

Much like other polymeric materials the stress strain behavior of stretch film is utilized to characterize its performance. During primary stretch the stiffness and elongation of a material are evaluated. Stiffness is a product of the material's stress-strain behavior (Figure 1). Elongation of stretch wrap leads to the film moving beyond its elastic limit and reaching non-recoverable deformation. When a film reaches permanent deformation it then undergoes strain hardening, and its tensile strength increases dramatically [6]. As the film is stretched it begins to be more resistant to further stretch and provide higher levels of containment per revolution. The more film is elongated before being applied to the load, the less stretch capacity that remains in the film, allowing for less ability to further stretch during the distribution cycle. Increasing primary

Table 1. General stretch film characteristics

Film Attribute	Cast Film	Blown Film
Clarity	Clear	Hazy
Noise	Quiet	Loud
Puncture / Tear Resistance	Medium / High	High / Low
Load Containment	Medium	High

stretch facilitates greater overall yield-- more loads to be wrapped per roll, less film waste, and lower overall consumption. Due to these load securement and cost benefits primary stretch levels of 250% are becoming standard [7].

Secondary Stretch

Secondary stretch is defined as further elongation between the carriage and the load being wrapped. Secondary stretch is a more difficult process to maintain in application. Secondary stretch occurs when there is either more or less film provided as compared to perimeter of the load (Figure 2). Positive secondary stretch can lead to film breaks or can potentially damage the product being stretch wrapped; conversely, negative secondary stretch can lead to instability of a load.

To illustrate this, if there is 10% less film provided compared to load length, the secondary stretch level will be positive 10%. When there is less film provided than necessary to cover the surface of the load the film must react by further stretching in order to accommodate. If there is more film provided than perimeter of load there will be an excess of film around the load leading to negative secondary stretch. In a secondary stretch state there are three scenarios for the dissipation of energy: reduction of surface area to cover by means of moving or compressing product, elongation of material to distribute energy over a larger area, or failure leading to a film break [8].

Positive secondary stretch helps to provide the initial resistance to the movement of a load, by creating compressive force on a load's four corners. For a 48" x 48" load with zero percent tension and slippage the length of film fed would be 16 feet per revolution around the load. At a 20% tension setting the film being dispensed decreases based on the motor response, leading to less film dispensed than perimeter of the load being wrapped. The film compensates for this, leading to positive secondary stretch and increased compressive force along the corners of the load.

Compressive Force of Stretch Film

Compressive force can be defined as the inward force that a film exerts on a load. This inward force is highest at the corners of a load, because this is where a film achieves its maximum stretch during the wrapping cycle. Compressive force is a unitizing force that increases with more secondary stretch. Figure 3 illustrates the effects of positive

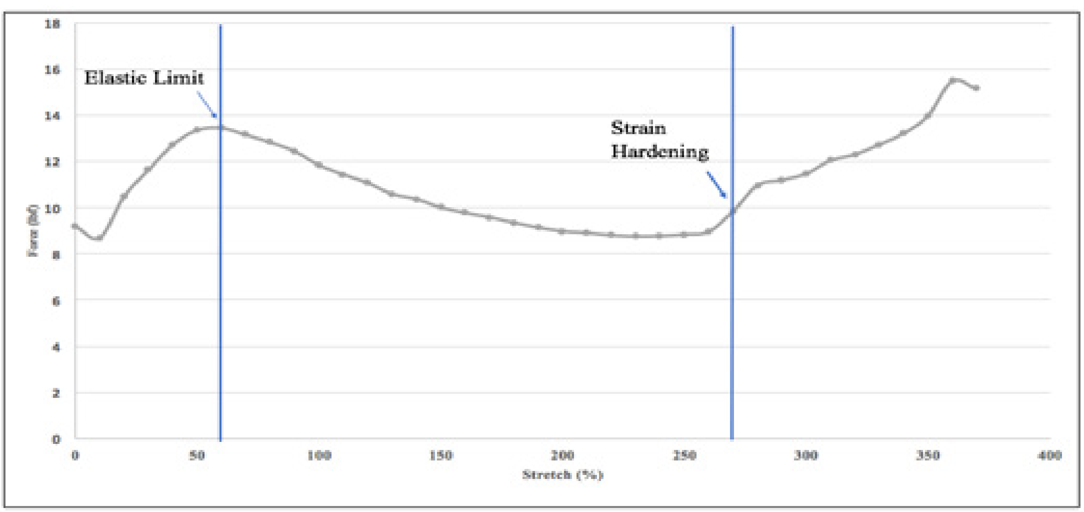

Figure 1. Stress-strain behavior of stretch film

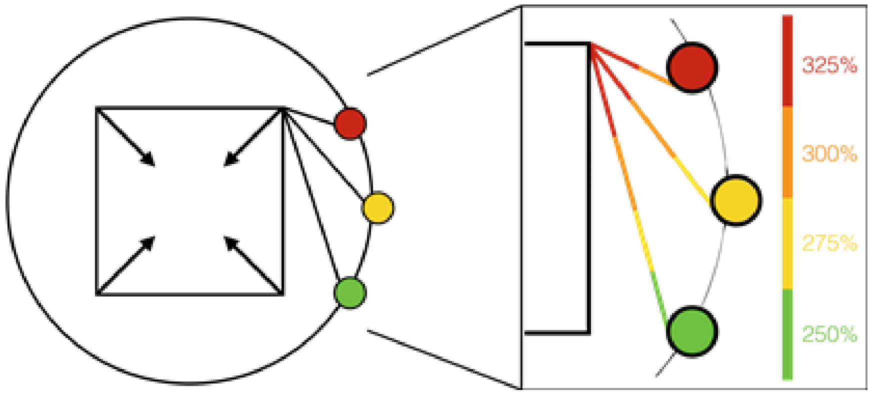

Figure 2. Illustration of secondary stretch

secondary stretch. Too much compressive force can potentially damage corrugated boxes or light loads like tissue paper, whereas heavy rigid loads need high compressive force to keep the unit together during transit. Understanding how compressive force changes after a load is stretched wrapped is important for determining how a load will handle the rigors of the distribution environment. As a film recovers, its rigidity increases and the inward forces on the load decreases overtime [9]. This trend is important to understand how to properly stretch wrap unit loads.

Equipment to evaluate stretch film application

The Highlight Transportable Test Pallet is one system that can be used for evaluating stretch film application (Highlight Industries, Wyoming, MI USA). Figure 4 illustrates the Transportable Test Pallet System. This system is capable of collecting and analyzing different stretch film properties, including puncture, containment force, and compressive force, which are beneficial to both the film manufacturer and end user of stretch films [10]. In addition to determining film properties, this style of equipment can also be used as a quality control measurement device.

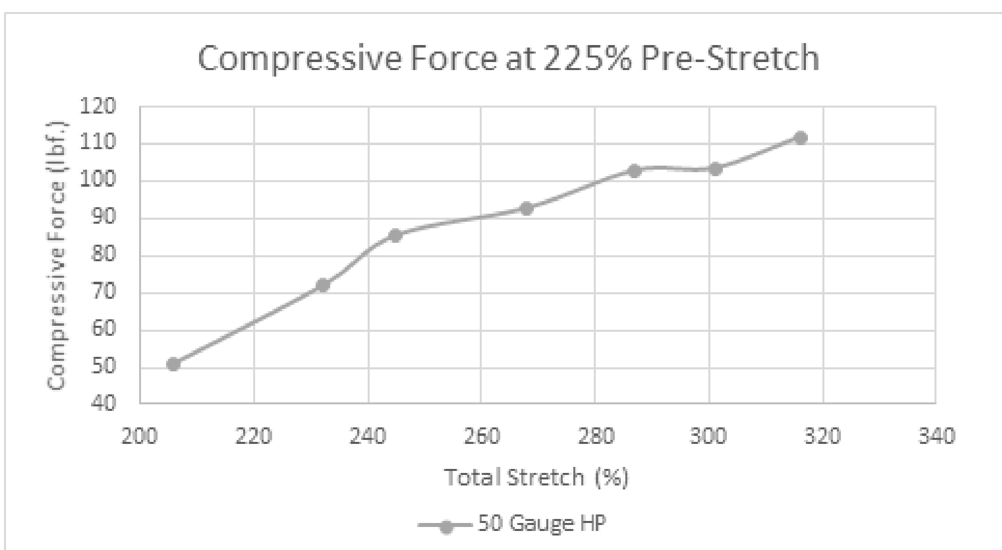

Figure 3. Compressive Force at Increasing Secondary Stretch Levels

The objective of this research study is to understand the post wrapping characteristics of stretch film. The study will focus on the use of industry leading high-performance cast and blown stretch films to determine how the compressive force of the stretch wrap changes as a function of time after being applied to a simulated unit load.

MATERIALS AND METHODS

A Materials Usage Standards Tracking (MUST) monitor (Atlantic Packaging Corporation, Wilmington, NC USA) was used in this study to measure the amount of total stretch as the film was applied to the unit load. This type of monitor utilizes structural, sensory, and electronic/electrical components to generate different measurements relating to stretch wrap usage [11]. The monitor outputs measurements for ounces of film applied, average total stretch, and total revolutions during the cycle. The Highlight Synergy IV Wrapper was outfitted with a MUST monitor to use with the Highlight Industries Transportable Test Pallet to give accurate measurements and repeatable results.

This evaluation involved a high-performance cast (HP cast) stretch film commonly used to contain loads for shipment and a high-performance blown (HP blown). The HP cast film was characterized as having the ability to stretch beyond 275% ultimately having a wider working region of the film. The high-performance blown was characterized as having high puncture resistance and an ability to stretch up to 275%. Both films were tested at positive and negative secondary stretch levels. The stretch films designated for this project are described in Table 2.

The selected films were applied to the perimeter of the Highlight Transportable Test Pallet using a Synergy 4 Highlight Stretch Wrapper. Table 3 displays the stretch wrapper setup parameters used for this evaluation. Upon successful wrapping of the test pallet, the system was activated to record the force being applied to the corner of the simulated load. The compressive force of the test pallet was monitored to see how the forces changed over time with both positive and negative secondary stretch.

Figure 4. Highlight Transportable Test Pallet

The films were applied to the load at values of 200% and 225% pre-stretch at both negative and positive secondary stretch levels. The MUST monitor was used to calculate the average total stretch throughout the wrap cycle. The tension (film force) settings at negative on pallet levels were set to achieve approximately 10-15% absolute negative stretch (i.e. 200% PS and 185% on pallet levels). For positive-post stretch the tension levels were set to achieve an additional 25% positive secondary stretch.

RESULTS AND DISCUSSION

Tables 4 – 5 and Figures 5 – 8 illustrate the results collected during the research experiment. Differences were observed in the film's behavior. The results revealed there were differences in how the films behaved based on whether it was applied to the load with positive or negative secondary stretch. The average change at positive secondary stretch after two hours of testing was a decrease of 16.3% for the HP cast and 15.7% for the HP blown. Both films showed similar decreased levels of a compressive force drop after the two hours of initial testing, when measured on top load cell on the Highlight Transportable test pallet. When the loads were applied with negative secondary stretch the compressive force increased over time. These changes were minimal, but consistent between both the cast and blown stretch films. The HP cast increased 2.8% and the HP blown increased 3.3% upon completion of the two hours of testing.

Table 2. Stretch film parameters

Manufacturer	Material ID	Thickness (Gauge)	Roll Width (in.)
A	HP Blown	60	20
A	HP Cast	50	20

Table 3. Stretch wrapper parameters

Number of top wraps	6
Pre-stretch (%)	200 and 225
Secondary stretch (%)	-15 and +25
Turn table speed (rpm)	20
Carriage speed (%)	60
Number of revolutions	17

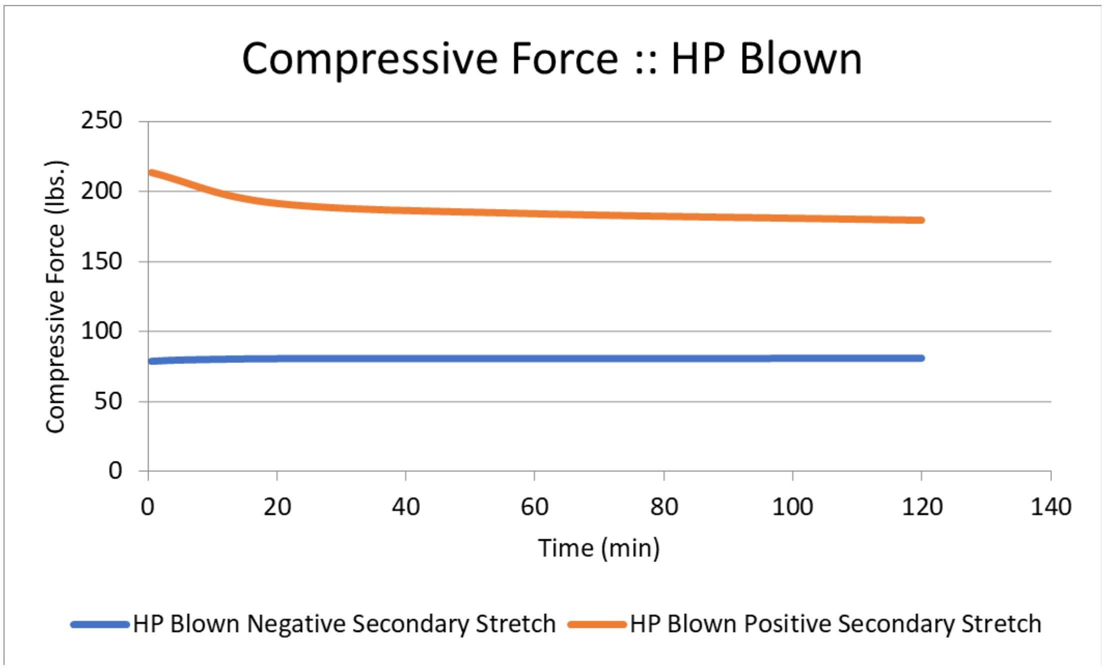

Figure 5. Blown 200% PS Compressive Force

Table 4. Compression force recordings for HP Blown 200% PS

Time (min)	Negative SS	Positive SS
0.5	78.5	213.3
20	80.7	191.6
60	80.7	184.4
120	81.1	179.7

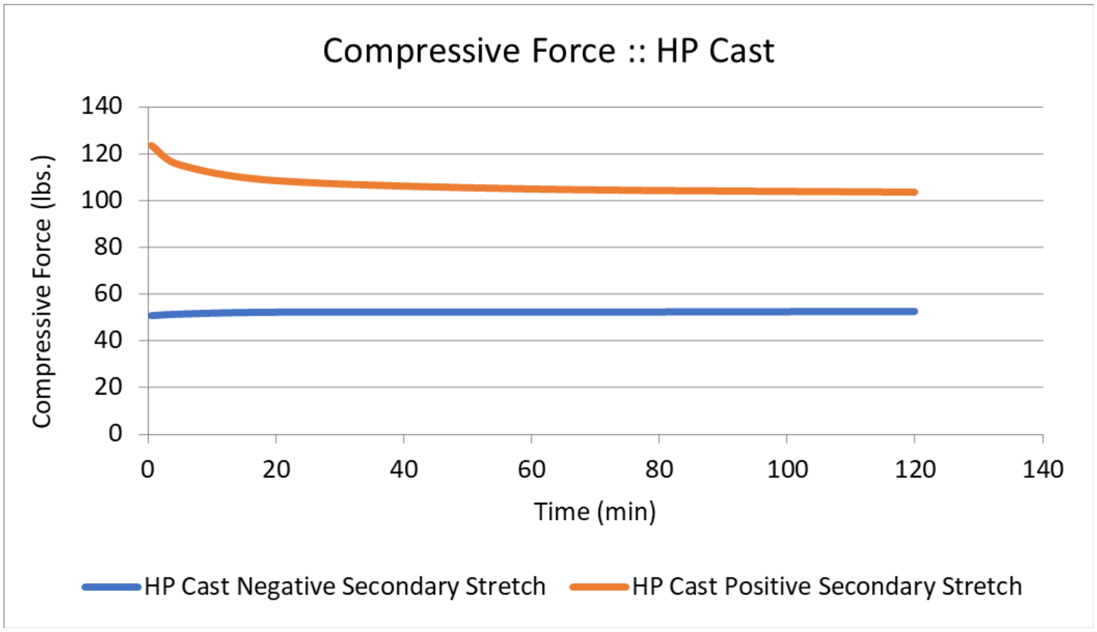

Figure 6. HP Cast 225% PS Compressive Force

Table 5. Compressive force results for HP Cast 225% PS

Time (min)	Negative SS	Positive SS
0.5	51.0	123.6
5	51.5	115.2
20	52.2	108.5
60	52.2	104.9
120	52.4	103.4

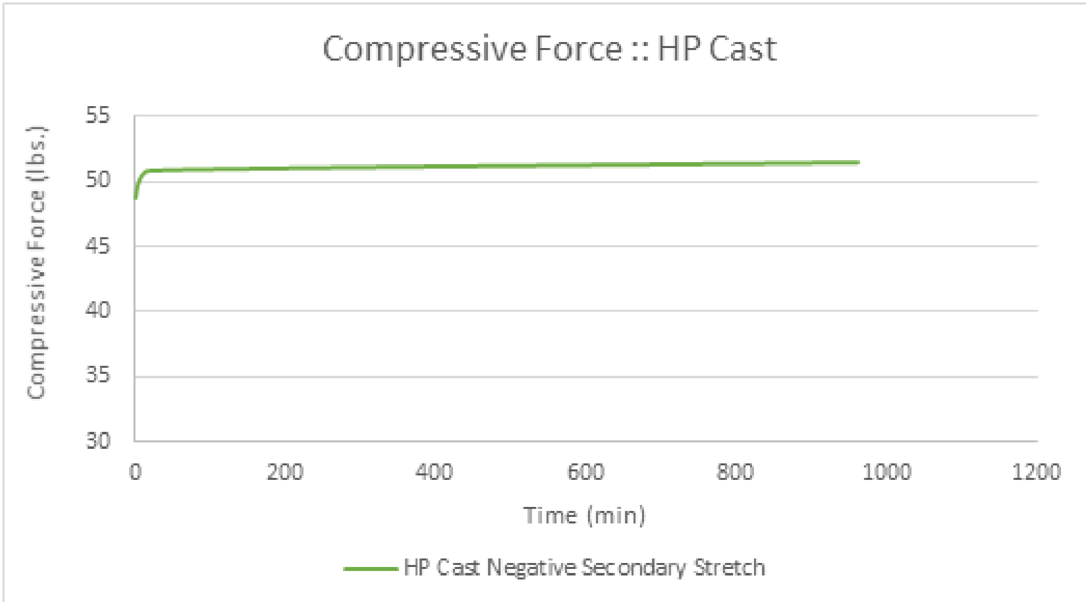

Figure 7. Negative secondary stretch for HP Cast

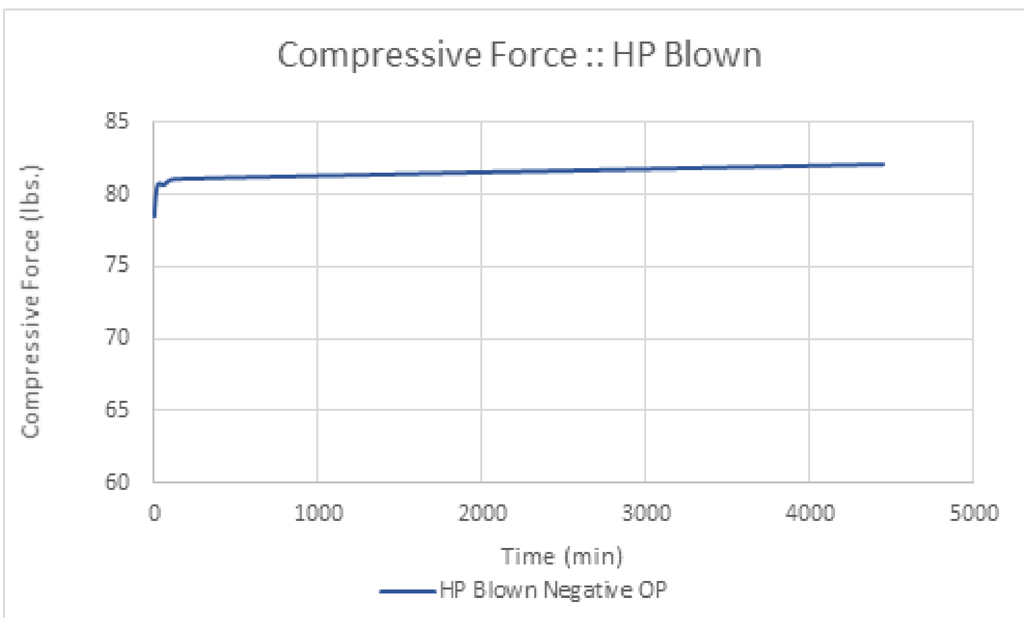

Figure 8. Negative secondary stretch for HP Blown

This initial data set revealed the majority of change at positive secondary stretch occurs within the first hour of testing. Between the first hour and the second hour of testing the decrease in compressive force noticeably slowed down for both films. Test results showed that if a load is applied with negative secondary stretch, the compressive force on the corners of the load can increase slightly overtime. A more detailed analysis of these trends based on a film's composition could be explored to understand how post-wrapping application of stretch film varies based on the polymeric structure of a film.

To develop a properly optimized unit load, it is imperative to understand how stretch film behaves over time and the interaction it has with the unitized load of packaged products. If applied with negative secondary stretch, the forces after initial wrapping were shown to increase 3% within the first two hours. Further evaluation of the stretch film was completed to determine how these forces would change during a period of extended warehousing (Figures 7 and 8). Tests measuring the compressive force were executed for 16 hours on the cast film and 69 hours on the blown film in order to fully understand the trends one would see after completion of the wrapping cycle. From hour two to hour 16 there was an additional 1.3% increase for the cast film with a total of 2.8% percent. For the blown film from hour two to hour 69 of testing there was also a 1.3% increase in compressive force leading to a total of 4.6% rise in total force during the duration of testing.

CONCLUSION

This examination of post-wrap behavior of stretch film revealed changes in compressive force on a unitized load vary depending on how stretch film is applied. The biggest contributing factor influencing these changes is secondary stretch. If a load is stretch wrapped with positive secondary stretch the decline in compressive force was 15% after two hours of testing. Loads stretch wrapped with negative secondary stretch have an opposite effect, leading to an increase in compressive force of 3%. Even though there was an increase, the loads with positive secondary stretch will always be higher than those with negative secondary stretch. Trends were comparable for the tests completed at 16 and 69 hours. Overall results from this study showed the largest percent change in compressive force takes place within 120 minutes after the stretch film has applied to the load.

The information acquired in this study better helps end users understand how stretch films will behave after applied to a unit load, for periods of extended warehousing. This study showed the compressive force changes very quickly after being applied to the load with positive-secondary stretch and then reaches an equilibrium point where the changes in forces greatly slow down. These results indicate the pre-conditioning time of at least 72 hours recommended by some packaging standards could be reduced, due to the stretch films reaching equilibrium far quicker [12 and 13]. Further studies can be done at elevated temperatures and humidity levels, to reveal how various warehousing conditions can also play a role in post-wrapping behavior.

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