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RESEARCH ARTICLE

Evaluation of stretch film behavior during long-term storage under different atmospheric conditions

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ABSTRACT

This study examined the post-application behavior of two 20.3 micron machine stretch films, one categorized as high-performance and one as general-performance, for thirty days while stored at either 23°C or 38°C. For each film type, the stretch film was applied to a simulated unit load to produce neutral and positive applied total stretch scenarios. The relaxation curves developed from each test indicate the relaxation rate of the films varied based on the storage condition. Observed was an average of 41% containment loss for both high-performance and general-purpose films when the simulated loads were stored at 38°C. For simulated loads stored at 23°C, the reported average containment loss for both films was 26%. The application of the film, either neutral or positive, did not greatly affect the percent loss in containment for the film. Additionally, results showed the greatest amount of containment force loss occurred during the initial 2 h of storage for all 23°C treated samples and 38°C general-purpose treated samples, while 38°C high-performance films continued to relax for 7 days until no difference was observed.

KEY WORDS

Stretch film, containment force, storage temperature, storage duration

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1.0 INTRODUCTION

Unit load systems are the most predominant means for transporting packages through the global supply chain [1]. A unit load system is comprised of three components: pallet or shipping platform, packages, and the stabilizer [2]. Traditionally, the most common unit load system is comprised of a wooden pallet, corrugated containers, and stretch film. As this system is moved through the supply chain, it is subjected to hazards related to vibration, compression, mechanical shock and environmental factors. These hazards can adversely affect the performance of the unit load system. As a result, it is critical to understand how the unit load system and its individual components will respond to these different hazards in order to design an optimized unit load system.

In recent years, there has been a substantial amount of research related to understanding the performance of the unit load system against hazards related to shock, vibration, and compression. Molina et al., performed an investigation and found that by interlocking the corrugated containers on the pallet deck, the pallet deflection was reduced as compared to column aligned stacking [3]. Park et al., conducted a study and found that both package size and flute type can influence load bridging and pallet deck deflection during vertical top-to-bottom compression [4]. Further research has been completed to understand the dynamic response of corrugated containers as a function of different random vibration treatments [5], [6]. In addition to the effects of containers and pallets, recently published research related to stretch film found that the stretch wrap containment force significantly affected the deflection of stiffness on simulated pallets [1]. Dunno et al., reported the applied total stretch of the stretch film can influence the containers response during simulated vibration testing [7]. Singh et al., evaluated the effects of stretch wrap pre-stretch on unit load containment and concluded there were no correlation between the percentage pre-stretch and load containment during a simulated transport test [8].

When unitizing packages onto a pallet, stretch film is the most common load stabilizer due to its cost-effectiveness and capability to handle various load types [9]. There are two types of stretch film, hand and machine film, used within the packaging industry to secure loads for transport. Both film types can produced by either a blown or cast extrusion process. Cast film accounts for the majority of machine film used in the transport packaging market [10]. Each film extrusion process yields a stretch film providing different mechanical properties. In general, cast films are clearer and have greater tear resistance than blown films. Blown films typically possess higher puncture resistance and greater load containment than cast films when comparing similar formulations and gauges. Stretch films are typically selected based on the unit load type, but should also be based on warehousing and shipping environments [11].

The application of stretch film is a function of both primary and secondary stretch. Primary stretch is the pre-stretch ratio set on the stretch wrapper carriage, typically determined by a fixed gear ratio. Secondary stretch occurs between the load and the carriage in the form of tension, carriage speed, and rotational speed [12]. Total applied stretch is the actual stretch percentage after application to the load. The total applied stretch of the system yields three scenarios based on the relationship between total applied and primary stretch: negative (total stretch < primary stretch), neutral (total stretch □ primary stretch), and positive stretch (total stretch > primary stretch) [7]. To create the different total stretch scenarios, the secondary stretch is the factor more commonly altered as the primary stretch is controlled and held constant for most applications.

Following the application of the stretch film, the unit load systems can be stored for various lengths of times at different nodes in the supply chain, largely dependent on the product sector [13]. Wyns et al. quantified post-wrapping performance of stretch film, but the study was limited to using ambient laboratory conditions, ignoring factors such as storage temperature which could influence the containment force of the film [14]. Being able to accurately characterize the stretch film performance during long-term storage is vital to ensuring the secured cargo arrives to the customer safely and without damage. Another study explored the application of stretch film on a simulated unit load to understand the influence of wrap patterns and total applied stretch percentages using different grades of stretch film [14], [15]. These studies were performed at laboratory ambient environmental conditions. Based on the literature reviewed for this study, there is a need to better understand storage conditions and their effect on containment force.

One of the most common ways to evaluate stretch film application is through measuring its containment force. Containment force, as defined by ASTM D8314: Standard Guide for Performance Testing of Applied Stretch Films and Stretch Wrapping, is a measurement that's affected by multiple film characteristics, most notably compressive force and film stiffness (tensile forces) [16]. This standard defines a variety of tools and approaches to measure the containment force of stretch film after it has been applied to the unit load system. These systems can range from a simple steel plate or fingerstyle tool with a force gauge to the utilization of load cells or strain gauges to measure compression force over time. Although the containment force values do not indicate or predict the success of the unit load during transport, research has shown it to be a repeatable tool for performing comparative analysis between unit loads having undergone different wrapping applications [15].

The objective of this study was to examine the behavior of stretch film after application to a simulated unit load during long-term storage using different storage temperature profiles. To quantify this behavior, the containment force of stretch wrap was measured for thirty days at both elevated and ambient temperatures.

2.0 MATERIALS AND METHODS

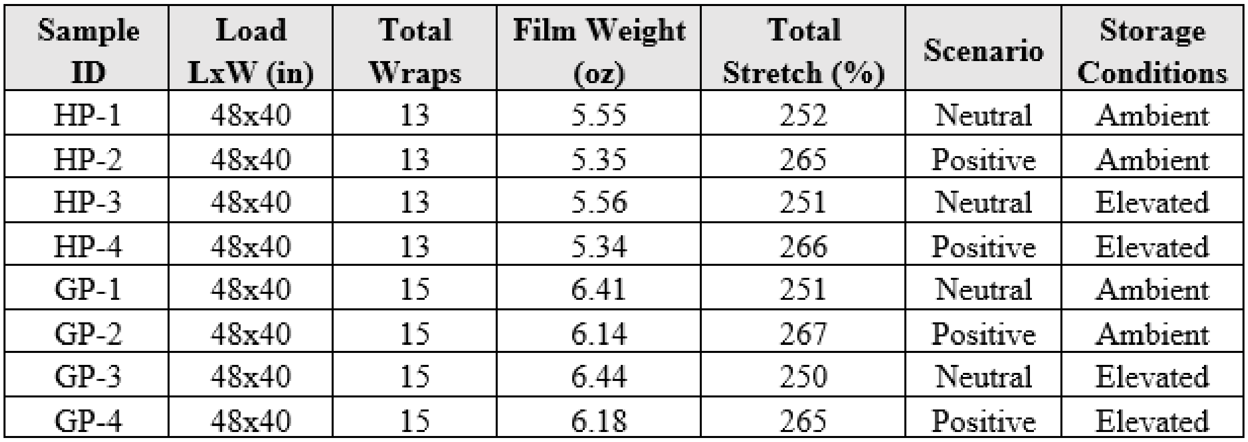
The containment force of films classified as high-performance and general-purpose stretch films was evaluated by observing the stress and relaxation of the polymer at elevated and ambient temperatures for an extended storage duration. Containment force is a quantitative measurement of the compressive inward forces of stretch film helping to keep the unit load stable [1]. The films used for this study were 20.3 micron cast machine stretch films. A high-performance (HP) film, and a general-performance (GP) film, were selected for use with this study. The HP film was produced using a high percentage of metallocene linear low density polyethylene (mLLDPE). The GP film was produced using a high percentage of linear low-density polyethylene (LLDPE). To reduce the bias and influence of the packaging materials on the stretch film, a wood crate was utilized to simulate the unit load (Fig. 1). By using a standard closed crate, the performance of the film could be isolated to determine the effects of the different storage conditions.

Figure 1. Simulated unit load used for research study

2.1 Equipment to evaluate stretch film

The Highlight Industries Portable Film Force System (PFFS) (Highlight Industries, Wyoming, MI USA) was employed to measure the containment force of the stretch film after application. The load cell device was attached to the crate according to the ASTM D8314 standard at a position of 18 in. from the center and 10 in. from the top of the load [16]. After zeroing the load cell, the simulated unit load was stretch wrapped and the Highlight Portable Film Force Kit Software recorded measurements for each test treatment.

Table 1. Stretch wrap and unit load parameters



Sample ID	Load LxW (in)	Total Wraps	Film Weight (oz)	Total Stretch (%)	Scenario	Storage Conditions
HP-1	48x40	13	5.55	252	Neutral	Ambient
HP-2	48x40	13	5.35	265	Positive	Ambient
HP-3	48x40	13	5.56	251	Neutral	Elevated
HP-4	48x40	13	5.34	266	Positive	Elevated
GP-1	48x40	15	6.41	251	Neutral	Ambient
GP-2	48x40	15	6.14	267	Positive	Ambient
GP-3	48x40	15	6.44	250	Neutral	Elevated
GP-4	48x40	15	6.18	265	Positive	Elevated

2.2 Stretch wrap application, storage conditions, and recording parameters

The unit loads were stretch wrapped using a RoboPac RotoPlat 707 stretch wrapper (RoboPac USA, Duluth, GA, USA). In this study, the pre-stretch (primary stretch) was held constant at 250%. To adjust the total stretch of the system, the secondary stretch parameters were changed to yield the different on pallet stretch scenarios, neutral and positive total stretch. Table 2 shows the stretch wrapping load parameters applied during testing. While there was a different number of total wraps used for the films selected, the area of measurement for this project was the top layer of the simulated unit load (note the position in Sect. 2.1). For each test sample, the number of top wraps were identical (3); the total number was adjusted to alter the total stretch percentage to yield the desired stretch scenarios. The total stretch for each of the unit load scenarios was calculated by performing a cut and weigh analysis using the Highlight Industries Stretch Tools Application (Highlight Industries, Wyoming, MI USA).

Two storage conditions were selected for this project. After application, the unit loads were either stored at ambient laboratory conditions or stored at elevated conditions inside a climate-controlled chamber. The ambient conditions were laboratory conditions ranging from 21-24°C and 38-43% RH throughout the duration of the study. The elevated conditions selected for this study were 38°C and 50% RH. For each of the storage conditions, the unit loads were stored for a period of 30 days.

The containment force was measured at predefined intervals for the duration of the experiment to understand the behavior of the stretch wrap for each application type and storage condition. The PFFS was used to capture the containment force at the following intervals for each scenario:

Table 2. Containment force values for High-Performance (HP) Film

Sample ID	Total Stretch	Storage Condition	0h (lbs.)	30d (lbs.)	Δ Force (lbs.)	Percent Loss (%)
HP-2	Pos	Ambient	23.5	17.3	6.2	26
HP-4	Pos	Elevated	22.7	13.6	9.1	40
HP-1	Neu	Ambient	20.6	15.8	4.8	23
HP-3	Neu	Elevated	19.7	11.9	7.8	40

Table 3. Containment force values for General-Performance (GP) Film

Sample ID	Total Stretch	Storage Condition	0h (lbs.)	30d (lbs.)	Δ Force (lbs.)	Percent Loss (%)
GP-2	Pos	Ambient	17.8	13.0	4.8	27
GP-4	Pos	Elevated	17.7	10.6	7.1	40
GP-1	Neu	Ambient	18.1	13.4	4.7	26
GP-3	Neu	Elevated	17.8	10.1	7.7	43

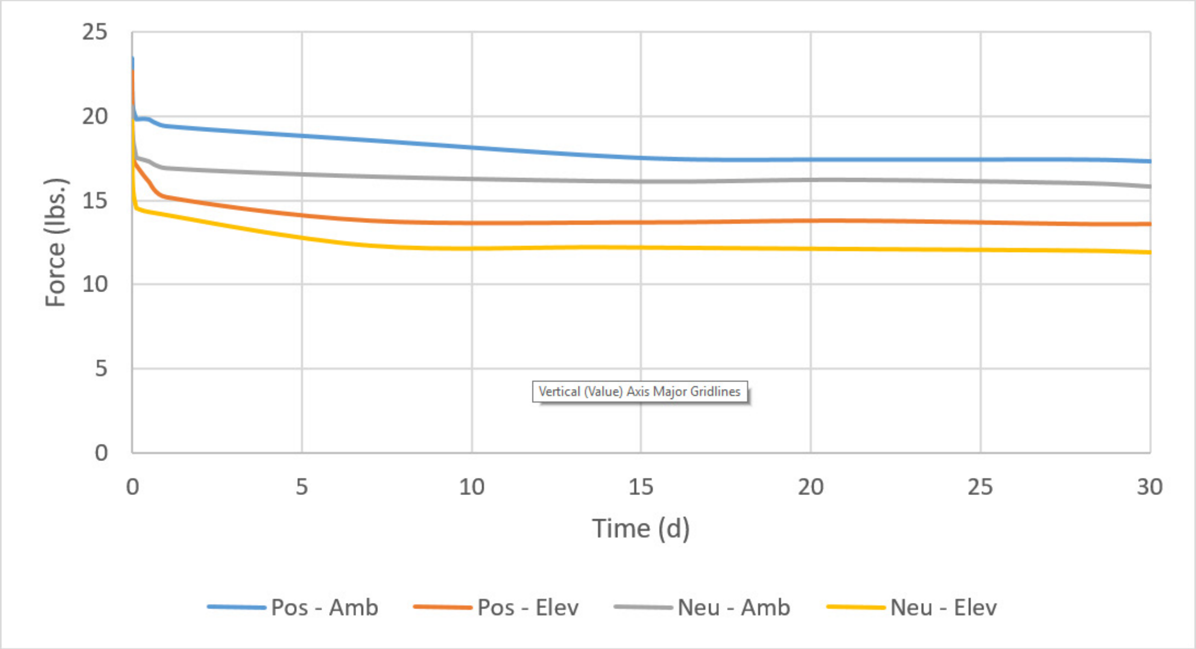


Figure 2. High-performance stretch film – PFFS

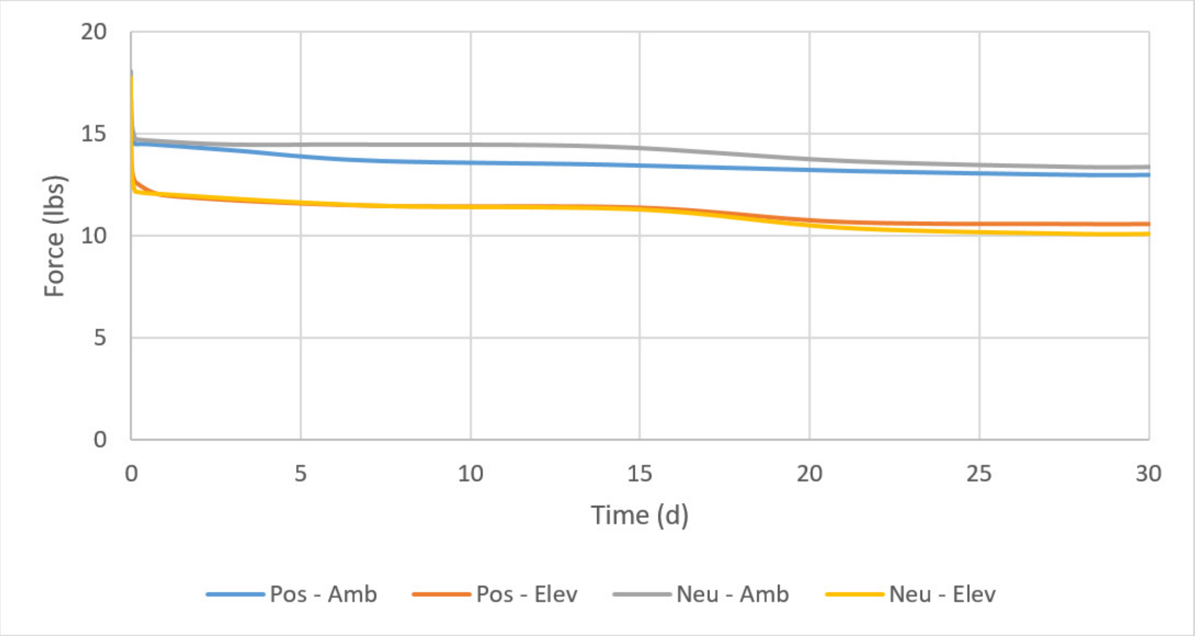


Figure 3. General-purpose stretch film – PFFS

0h, 3h, 24h, 7d, 21d, 28d, and 30d. From 0h to 3h, the portable film force system was programmed to record the relaxation of the film continuously. From there, the remaining points were collected statically throughout the remainder of the 30-day test.

3.0 RESULTS AND DISCUSSION

Tables 3-4 and Figures 2-3 illustrate the results collected from this research experiment. For each scenario and storage condition, there was a decrease in containment force over time.

It can be observed from Tables 3-4 and Figures 2-3 there was a loss in containment over time for each of the test parameters. Comparing the positive total stretch results of the ambient storage conditions (HP-2) to the elevated storage conditions (HP-4), the loss in containment was 26% and 40% respectively. This resulted in a percent difference of 38% when comparing the change in force over the period of study for the positive total stretch at the different storage conditions. These results show the containment force is largely affected by the storage conditions. Although storage conditions affect the loss in containment, when comparing the percent loss of the elevated neutral total stretch of HP-3 and the positive total stretch of HP-4, the effect of total stretch showed no difference, as both films reported a loss of in containment of 40%. This indicates that regardless of the total stretch application, both scenarios result in a similar loss in containment. The results were also observed for the neutral and positive total stretch for the loads stored in ambient conditions.

Results for the general-purpose stretch film were similar to those reported by the high-performance film. Comparing the positive total stretch results of the ambient storage conditions (GP-2) to the elevated storage conditions (GP-4), the loss in containment was 27% and 40% respectively. This resulted in a percent difference of 39% when

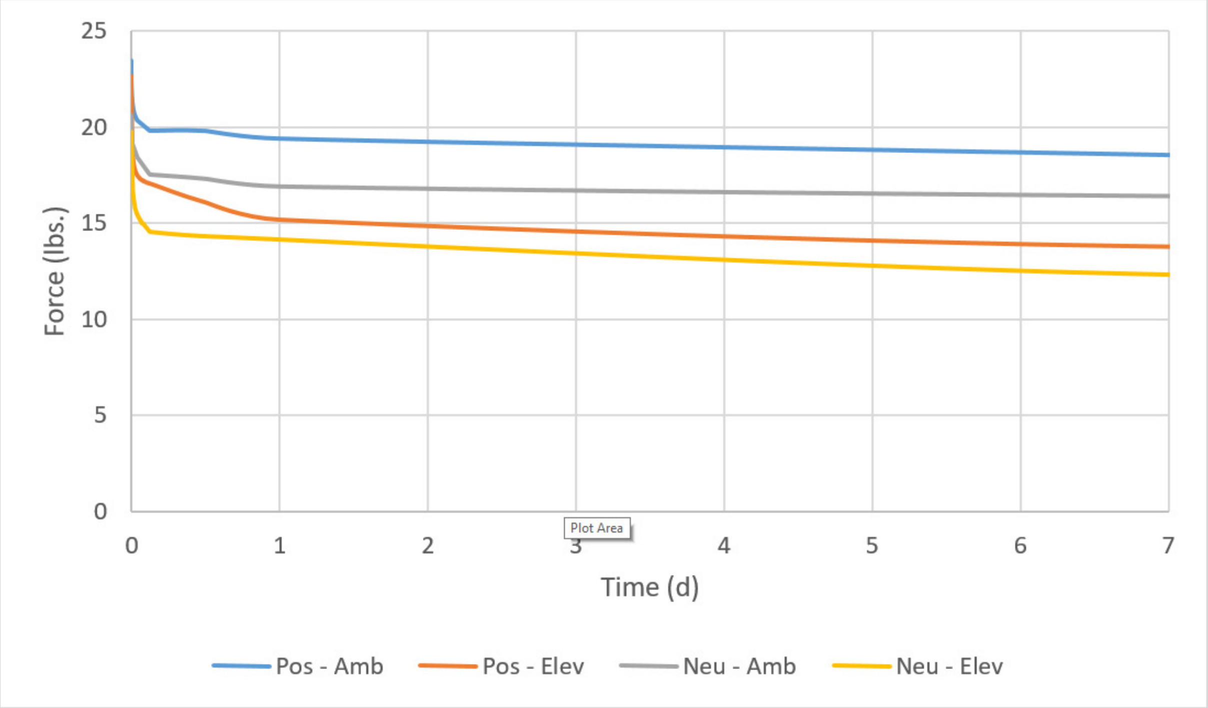


Figure 4. High-performance stretch film 7d after application

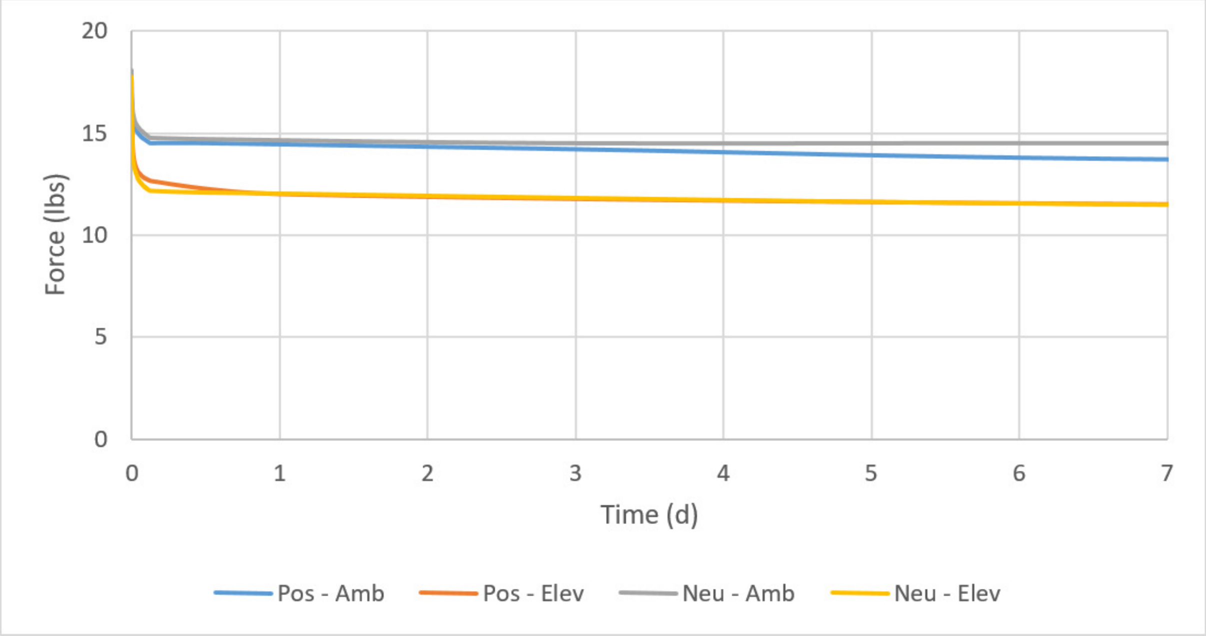


Figure 5. High-performance stretch film 7d after application

comparing the change in force over the period of study for the positive total stretch for the different storage conditions.

When comparing the two different film types, no differences were observed between total stretch and storage conditions. For this study, these observations showed no improvements were gained with the high-performance stretch film. Although the initial containment forces were higher for the high-performance films, the total percent loss between all of the parameters (storage and total stretch) were similar.

Figures 6 and 7 illustrate the high-performance and general-purpose films and their containment loss as recorded by the Highlight Portable Film Force System during the initial seven days. Results from this study showed the ambient conditions are in agreement with Wyns et al. who indicated the greatest percent change in the containment force occurs within 120 minutes after application [14]. For both the ambient high-performance and general-purpose films, 87% of the containment force loss occurred within the first 120 minutes. After 120 minutes, no statistical differences were noted for the duration of the study for the films stored at ambient conditions. The samples stretch wrapped with the general-purpose films and stored at elevated conditions behaved similarly to those at ambient conditions. The greatest percent change occurred during the first 120 minutes, with 73% of the containment loss occurring within the first 120 minutes.

In contrast, the high-performance films stored at elevated conditions continued to relax beyond 120 minutes. While there was a significant loss in containment force during the initial 120 minutes, the samples stretch wrapped with the high-performance film stored at elevated conditions continued to relax and did not reach equilibrium until Day 7 for both the positive and neutral applied total stretch. Leguebe et al. reported the residual stress levels of a stretch film were achieved within 15 minutes, but experimental results from this and previous studies show the stretch films do not reach equilibrium until much later after application [14], [17]. These findings can be of significance as prior research has indicated that unit loads will respond differently to inputs, such as vibration, and therefore it is critical to achieve a point of equilibrium in the stretch film application prior to both testing and shipping the unit load container through the supply chain [7].

4.0 CONCLUSION

Examined during this study were the effects of storage conditions on the containment force for two 20.3 micron machine stretch films. Two different categories of stretch film were evaluated; high-performance and general-purpose. A simulated unit load was used to complete all tests to isolate the performance of the stretch film while eliminating bias or influence of traditional packages which could be affected by storage conditions. The results from this study showed elevated temperatures greatly reduced the containment force of the stretch film after application, when compared to ambient storage conditions. The containment force was decreased at elevated temperatures, but no differences were observed between neutral and positive total stretch scenarios. The high-performance film resulted in an overall higher containment force as compared to the general-purpose film, but no differences were observed in the percent loss. Additionally, it was determined the majority of containment force loss occurred within the first 2 h of the testing for all of the ambient conditioned treated samples and the elevated general-purpose films. For the high-performance films applied to the simulated unit load and stored at the elevated conditions, relaxation continued until Day 7 for the neutral and positive applied total stretch, noting that these films were initially able to provide greater resistance to the storage conditions as compared to the general-purpose films. The observations from this project can be used by the packaging industry to understand how storage conditions can influence the containment force of the stretch film. Understanding the total loss and the percent loss for each test scenario can provide packaging engineers the ability to adjust containment force values to match those desired not just immediately after application, but throughout the supply chain.

5.0 REFERENCES

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