CHAPTER IV

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents a comprehensive analysis of the finite element method (FEM) simulations conducted to evaluate the protective performance of Natural Rubber Latex Foam (NRLF) nets for guava during drop-impact scenarios. The study focuses on three primary methodologies for stress analysis.

The maximum equivalent (von Mises) stress was quantified to determine the peak mechanical loads on the fruit tissue. This analysis was performed during drop tests conducted at a height of 200 mm for parameter design investigations and 100 mm for density reduction investigations.

The investigation focuses on three critical parameters

Filament diameter (2.5, 3.5, and4.5 mm)

Filament number (15, 20, and 25 filaments)

Foam density (345, 397, and 420 kg/m^3)

4.2 Parameter variation and result

This simulation utilizes the Finite Element Method (FEM) to analyze the performance of eco-friendly foam nets for guava protection during high-impact freefall drops (200 mm). The study compares two cushion materials: expanded polyethylene (EPE) foam, a popular choice for cushioning and packaging, and a new, eco-friendly alternative made from neutral rubber foam latex. The goal is to optimize the design of the foam net for guava protection by evaluating the damage caused by the external force exerted during the freefall drop. This optimization focuses on the size and number of filaments within the foam net.

EPE commercial cushions performance.

The finite element simulations conducted in this study demonstrate that the application of a commercial Expanded Polyethylene (EPE) foam cushion effectively reduces the peak stress experienced by guava fruits during drop impact compared to unpackaged conditions, as illustrated in Figure 4.1. Specifically, the maximum equivalent stress observed in the unpackaged guava was approximately 0.0821 MPa, whereas the guava cushioned with EPE foam exhibited a reduced peak stress of approximately 0.0774 MPa (Figure 4.3), representing a decrease of about 5.7%. This reduction indicates that the EPE foam is capable of partially absorbing and redistributing the impact energy, thereby mitigating the severity of localized stresses within the guava tissue.

The stress-time presented in Figure 4.2 further reveals that the peak stress occurs at approximately 0.016 seconds after impact, corresponding to the moment of maximum deformation, followed by a rapid stress decay, which is characteristic of elastic recovery behavior post-impact. Moreover, the comparison of stress distribution patterns between the two cases shows that while unpackaged guava suffered from concentrated stress regions (Figure 4.1a), the cushioned specimen displayed a more diffused stress field (Figure 4.1b), further corroborating the role of the foam in impact energy dispersion. While EPE foam demonstrated measurable stress attenuation, the comparatively modest degree of stress reduction indicates that its cushioning performance could be limited, especially for highly delicate fruits or at greater drop heights.

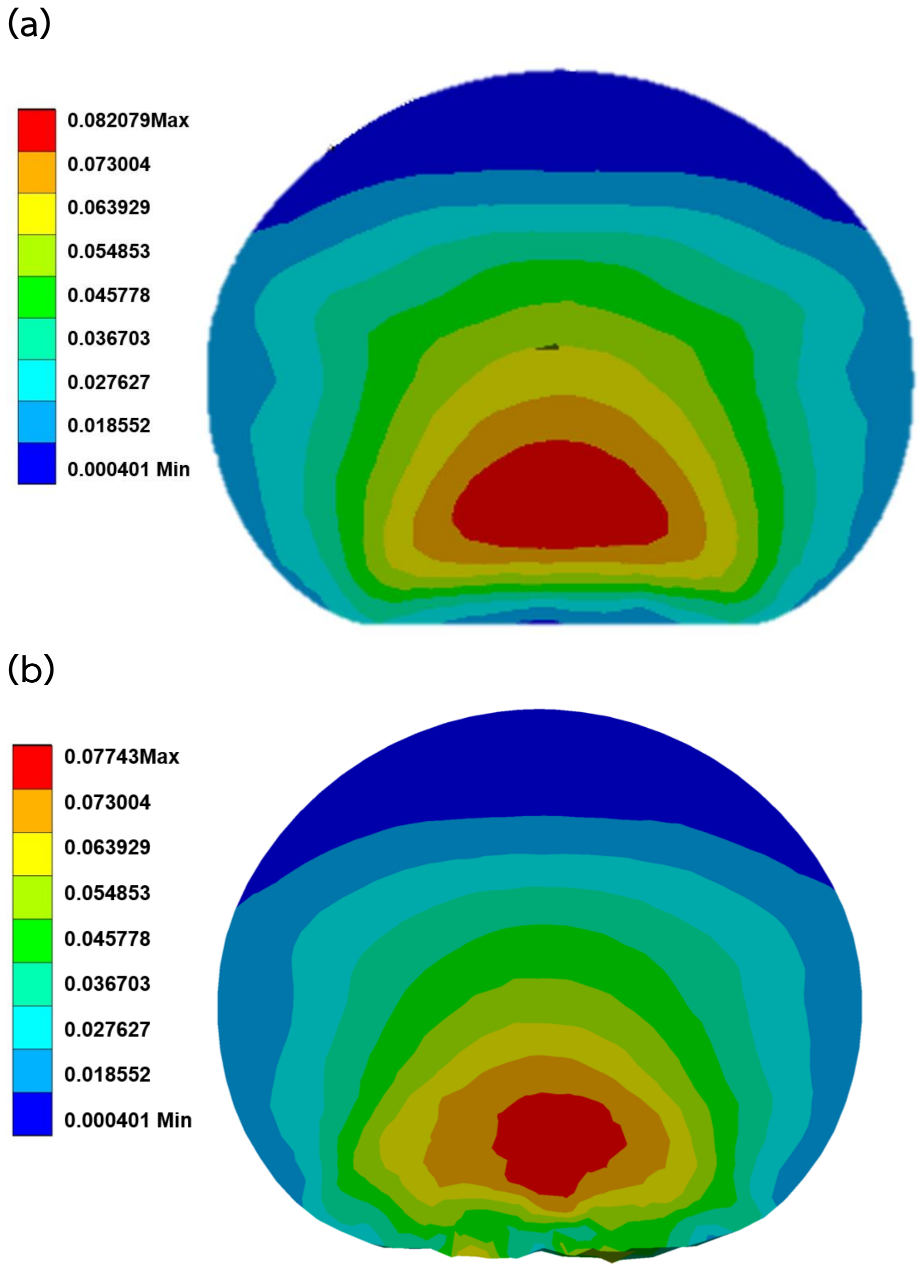


Figure 4.1 Stress [MPa] in the gravity direction for the drop height 200 mm model (a) guava unpacking (b) guava with EPE commercial cushion

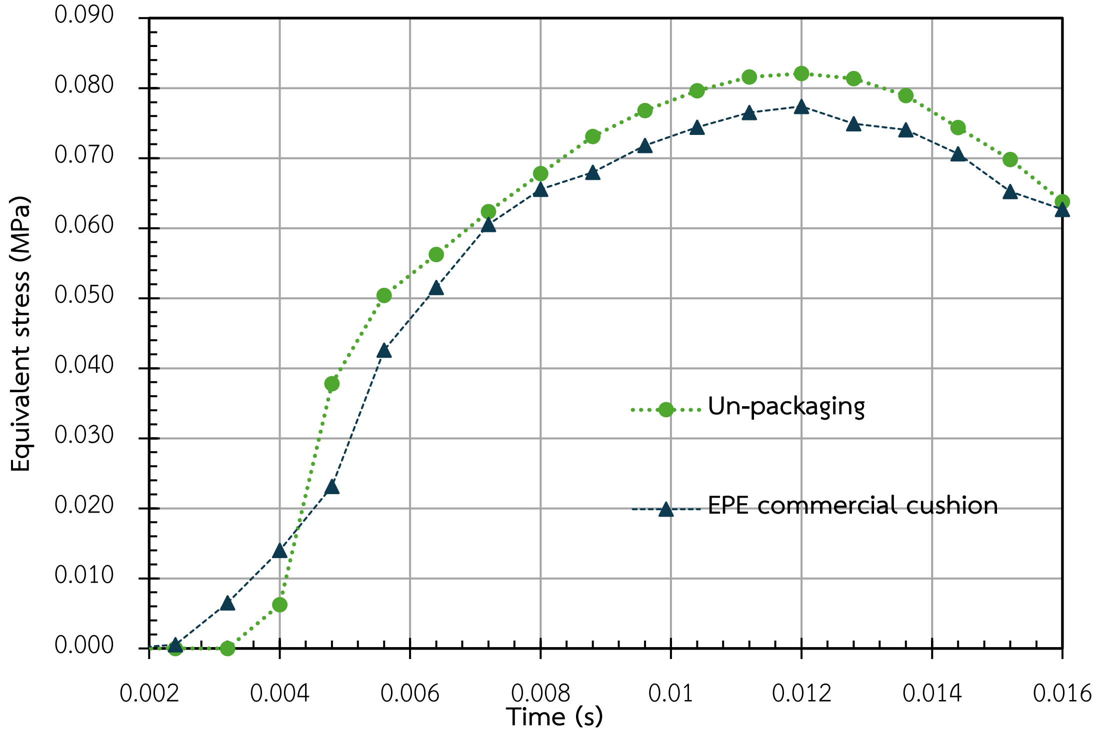


Figure 4.2 Maximum von-miss equivalent stress of guava and time at 0.016 s. drop height of 200 mm.

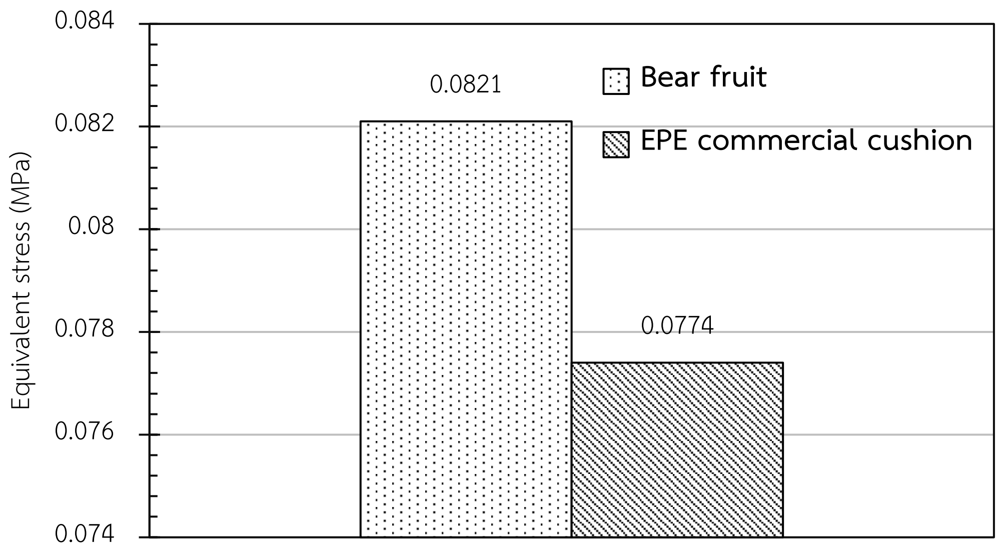


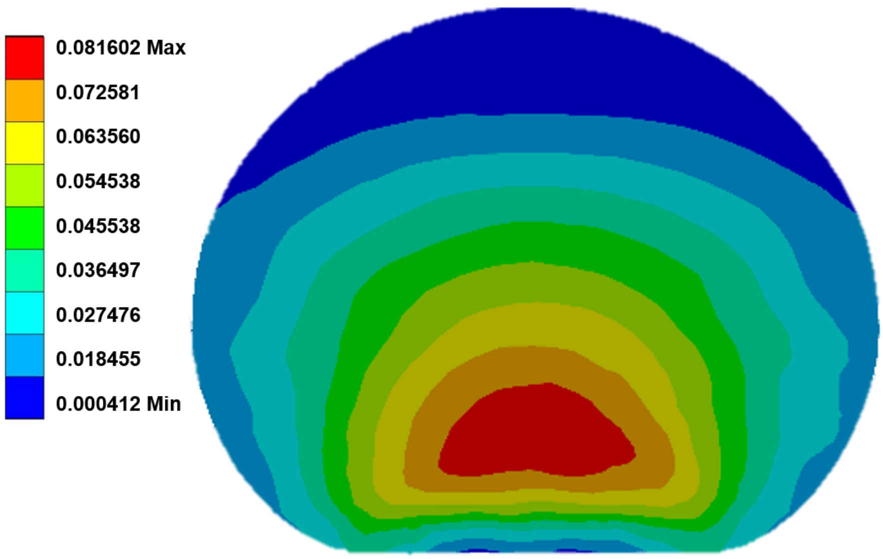
Figure 4.3 Maximum (von-miss) drop test of guava bear fruit compared to EPE commercial cushion foam net.

4.3 Effect of size and number on cushion performance.

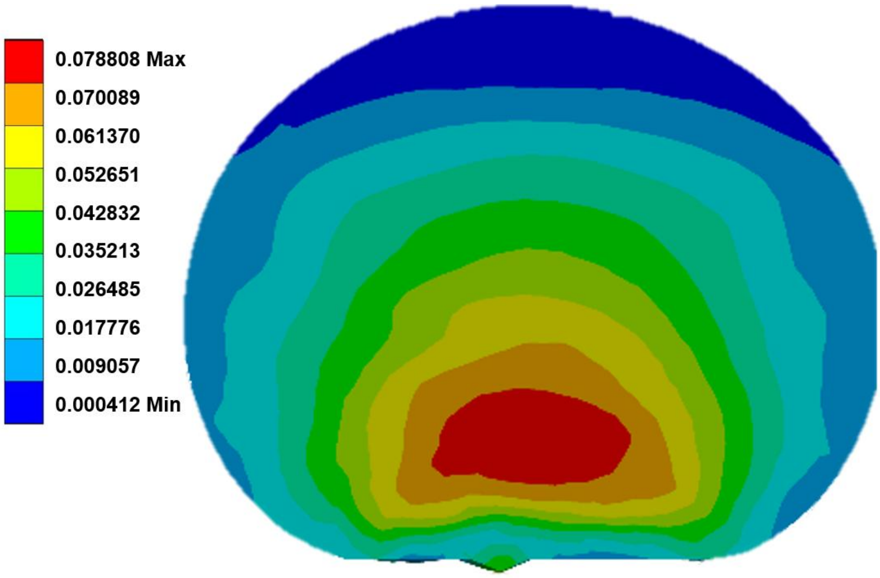
The performance of cushioning materials is heavily influenced by both the size and the number of constituent elements within the foam net structure. In this study, the impact of varying the filament size and number of filaments on the protective behavior of the NRLF cushion net was investigated under drop impact scenarios. Larger filaments and higher filaments number typically result in greater energy absorption capacity, potentially enhancing the cushioning effect. The investigation explores how these parameters influence the maximum stress and strain experienced by the guava fruit, providing valuable insights into optimizing the design of foam net cushioning for efficient fruit protection. By systematically varying the size and number of filaments, this study aims to determine the optimal combination that balances performance and material efficiency in preventing damage during drop events.

Filament dimeter 2.5 mm

(a)



(b)



(c)

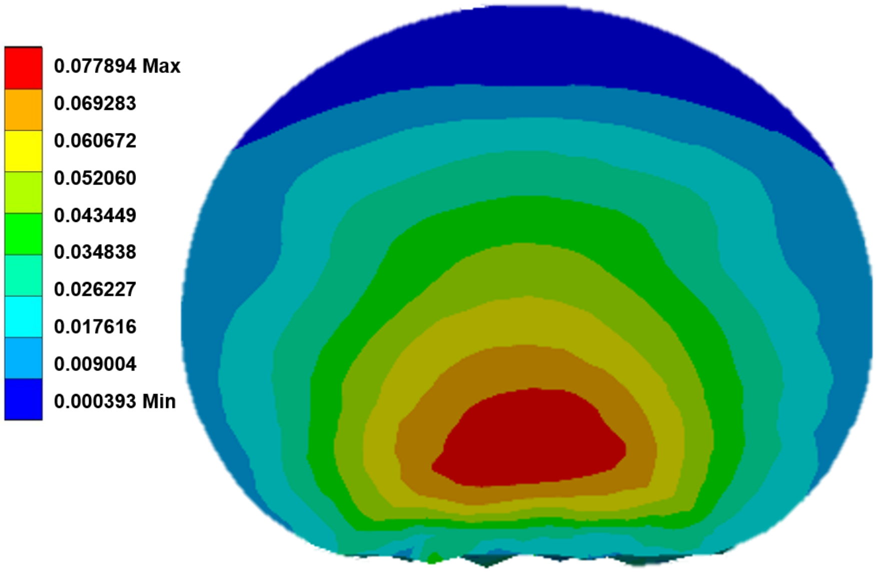


Figure 4.4 Stress in the gravity direction for the drop height model (a) NRLF 2.5x15, (b) NRLF 2.5x20 and (c) NRLF 2.5x25 from a cross-section view.

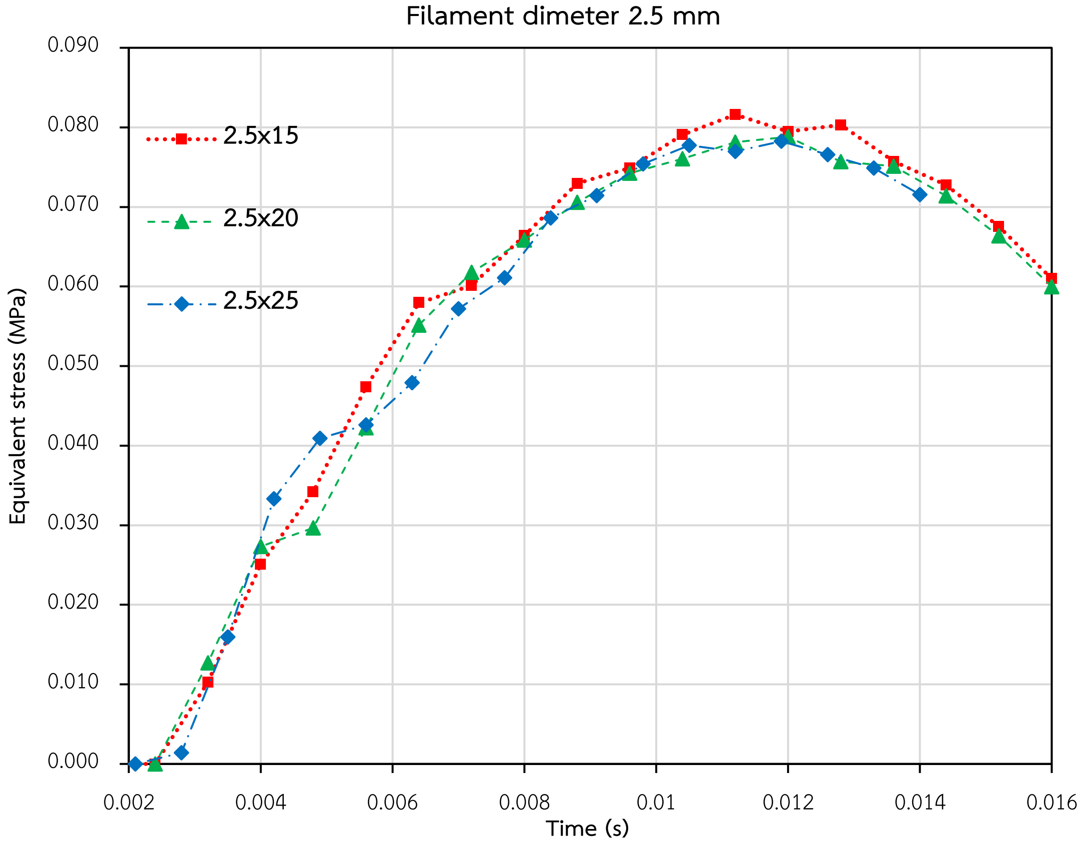
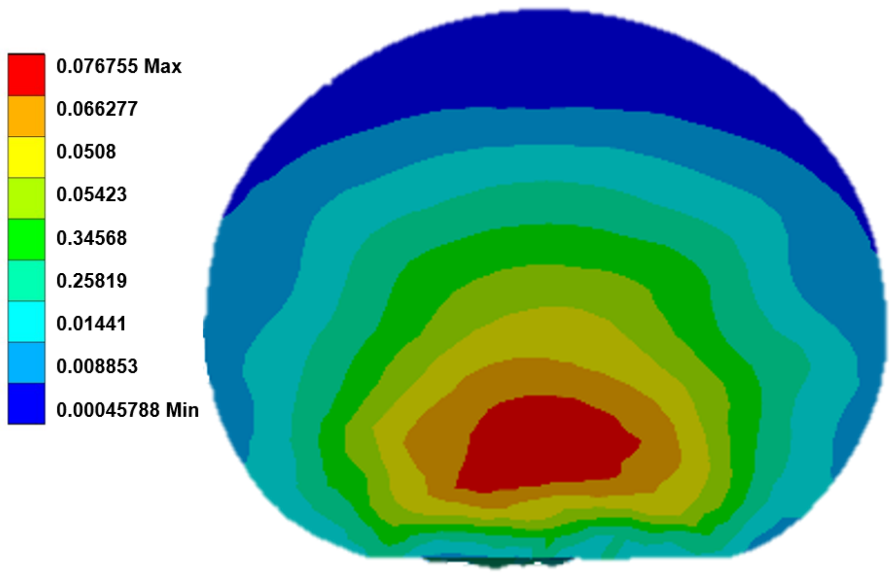


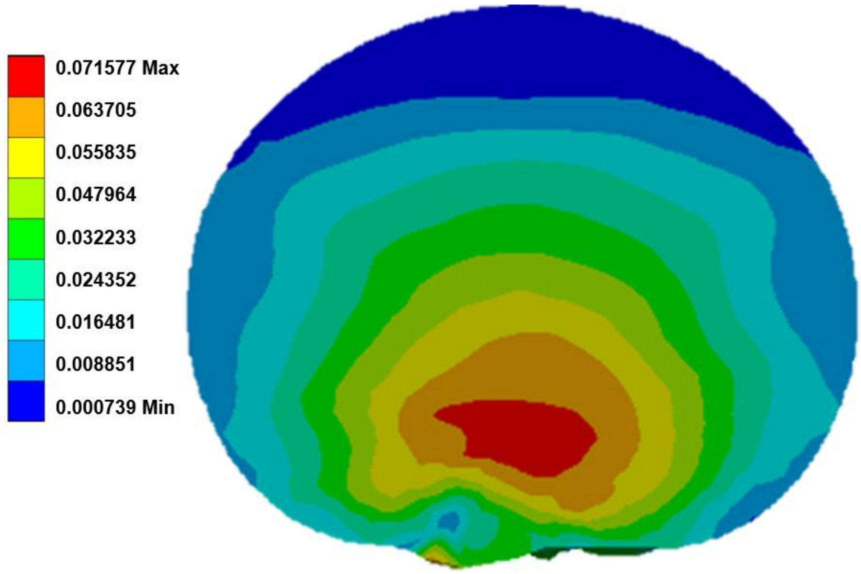
Figure 4.5 Stress distribution plots in guava sample (max von-mises stress, [MPa]) of NRLF foam net diameter filament size 2.5 mm.

Filament dimeter 3.5 mm

(a)



(b)



(c)

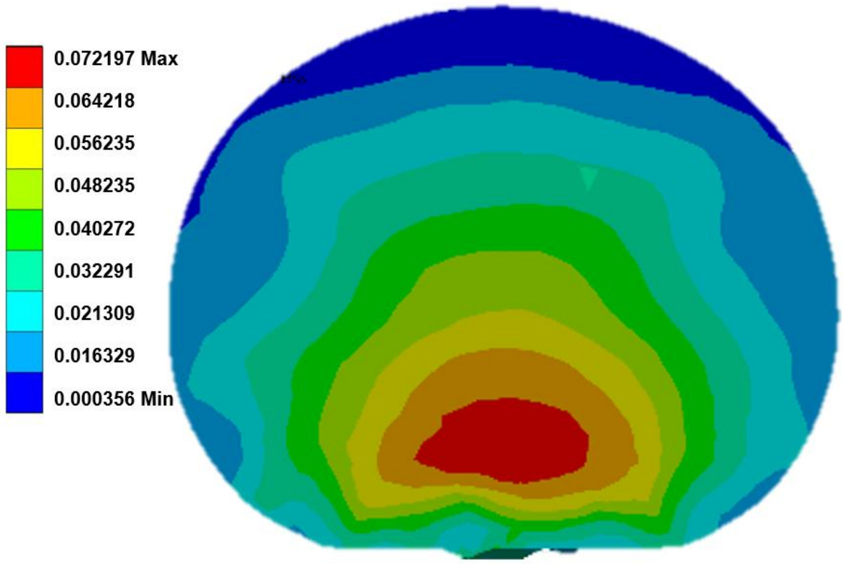


Figure 4.6 Stress [MPa] in the gravity direction for the drop height model (a) NRLF 3.5x15, (b) NRLF 3.5x20 and (c) NRLF 3.5x15 from a cross-section view show at time 0.0012 s.

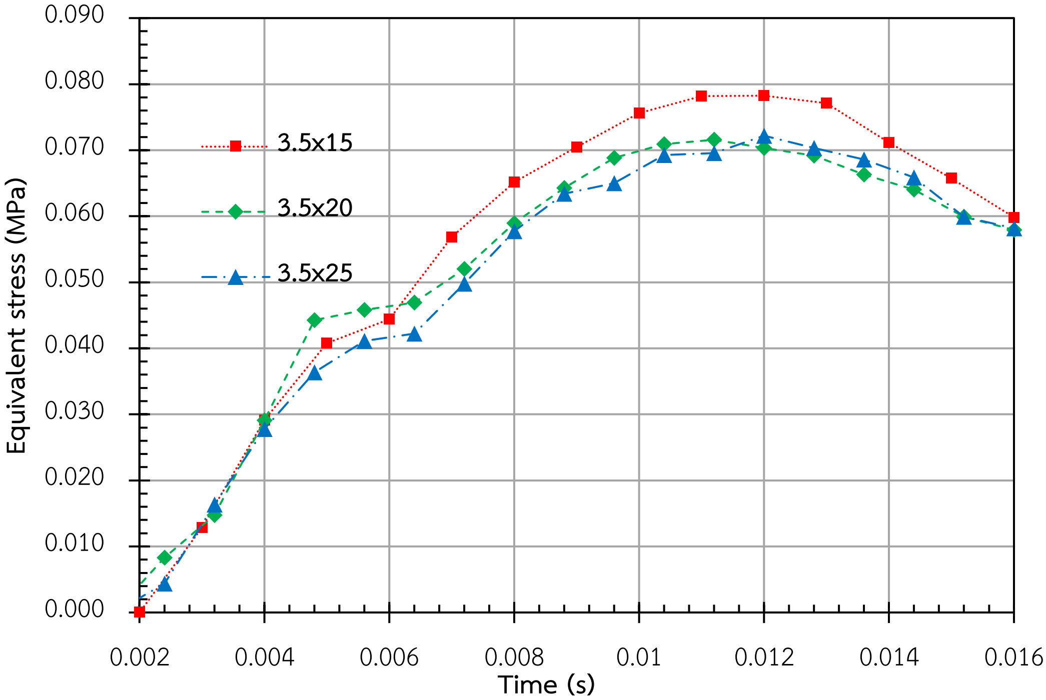
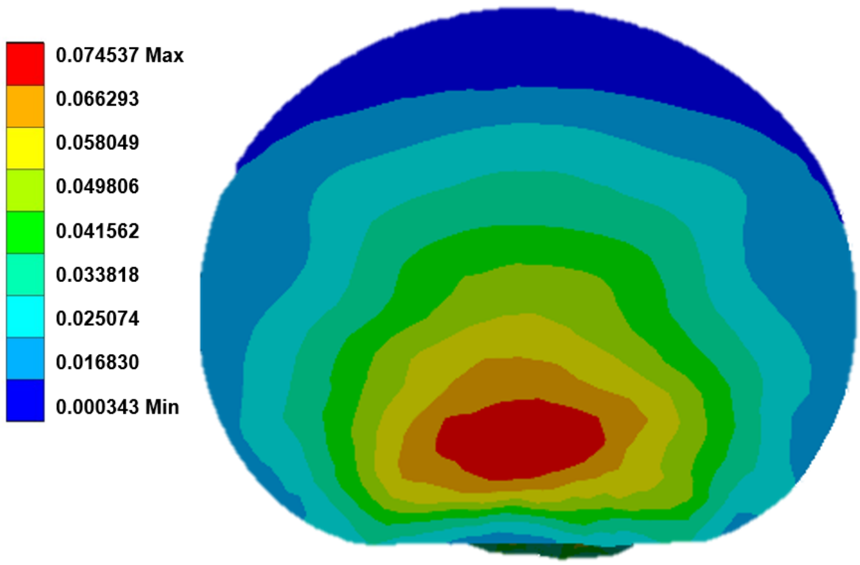


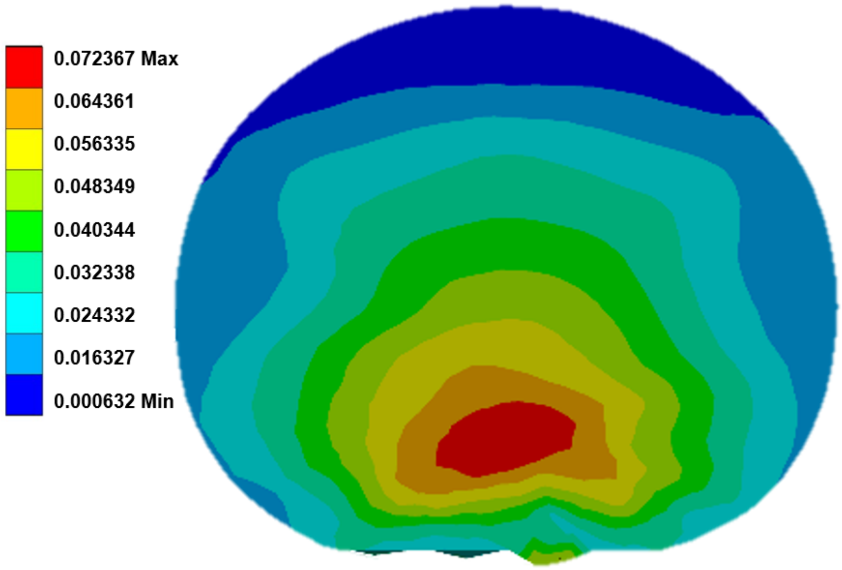
Figure 4.7 Stress distribution plots in guava sample (max von-mises stress, [MPa]) of NRLF foam net diameter filament size 3.5 mm.

Filament dimeter 4.5 mm

(a)



(b)



(c)

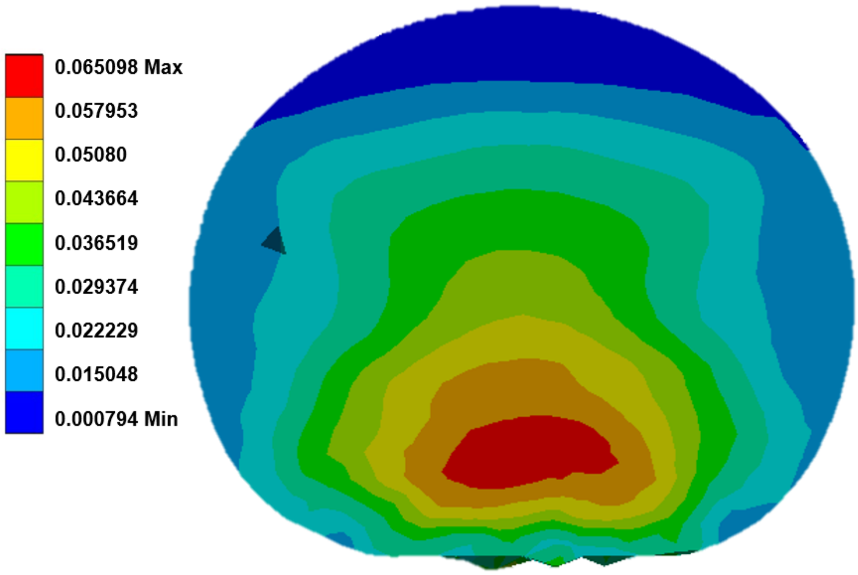


Figure 4.8 Stress [MPa] in the gravity direction for the drop height model (a) NRLF 4.5x15, (b) NRLF 4.5x20 and (c) NRLF 4.5x15 from a cross-section view show at time 0.0012 s.

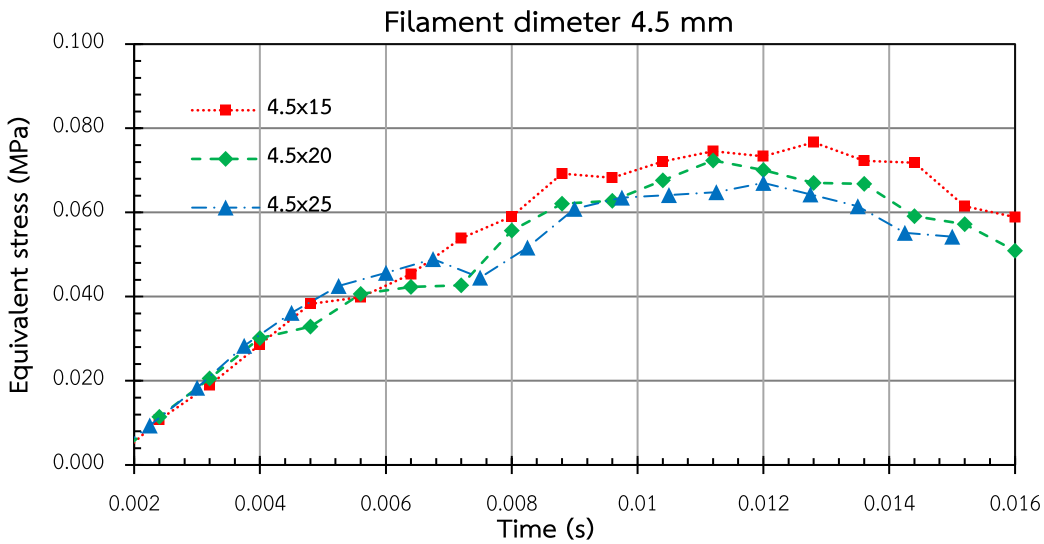


Figure 4.9 Stress distribution plots in guava sample (max von-mises stress, [MPa]) of NRLF foam net diameter filament size 4.5 mm.

Cushion performance results for NRLF 4.5x15 and EPE 3.5x25 cushions showed near-maximum stress. Increasing the number of filaments to 20 resulted in decreases of 5.9% and 7.0% in maximum stress, respectively.

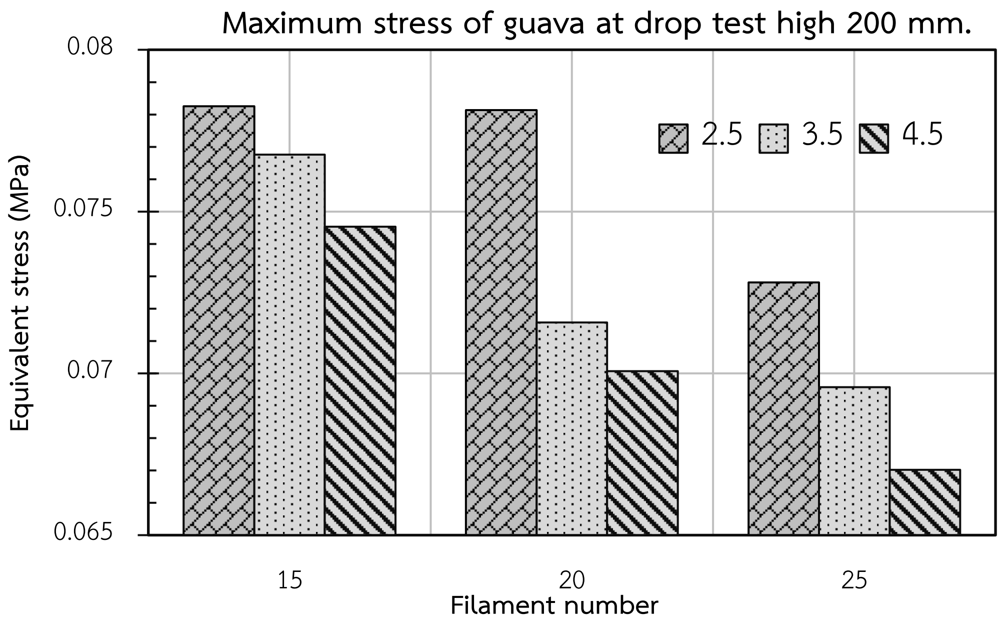


Figure 4.10 Maximum (von-miss) drop test of Guava NRLF packaging

The results from the drop test at a height of 200 mm Figure 4.11 show that the maximum equivalent stress experienced by the guava varied depending on the type and thickness of the cushioning material used. The unprotected guava (unpackaging condition) showed the highest equivalent stress, with a recorded value of 0.0821 MPa. This value serves as a baseline for comparison against other packaging configurations. When using filament materials of different thicknesses, a noticeable reduction in stress values was observed. The application of a 2.5 mm filament resulted in a stress value of 0.0728 MPa, indicating that even a relatively thin layer of cushioning can reduce the transmitted force to the fruit. Further improvement was seen with the 3.5 mm filament, which reduced the stress to 0.0696 MPa. The most significant decrease in stress was achieved with the 4.5 mm filament, which showed a value of 0.0670 MPa.

These findings suggest a trend in which increasing filament thickness corresponds with lower stress levels during impact. The data indicates that thicker cushioning layers are more effective at dissipating impact energy, thereby reducing the mechanical load transferred to the guava.

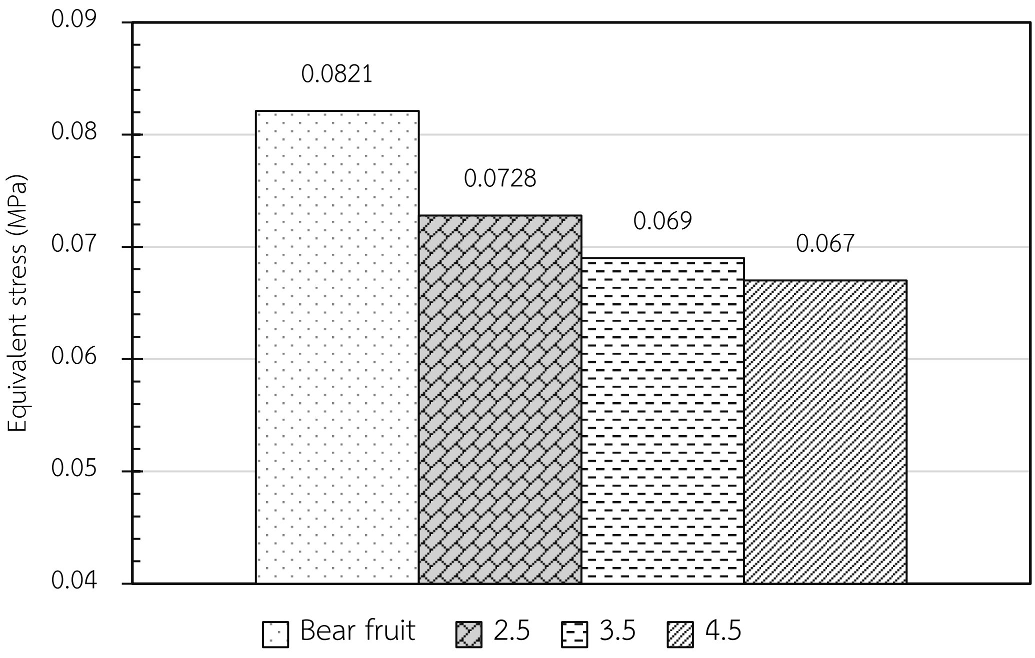


Figure 4.11 Maximum equivalent stress drop test 200 mm was observed at 0.013 s after impact and NRLF filament number 25.

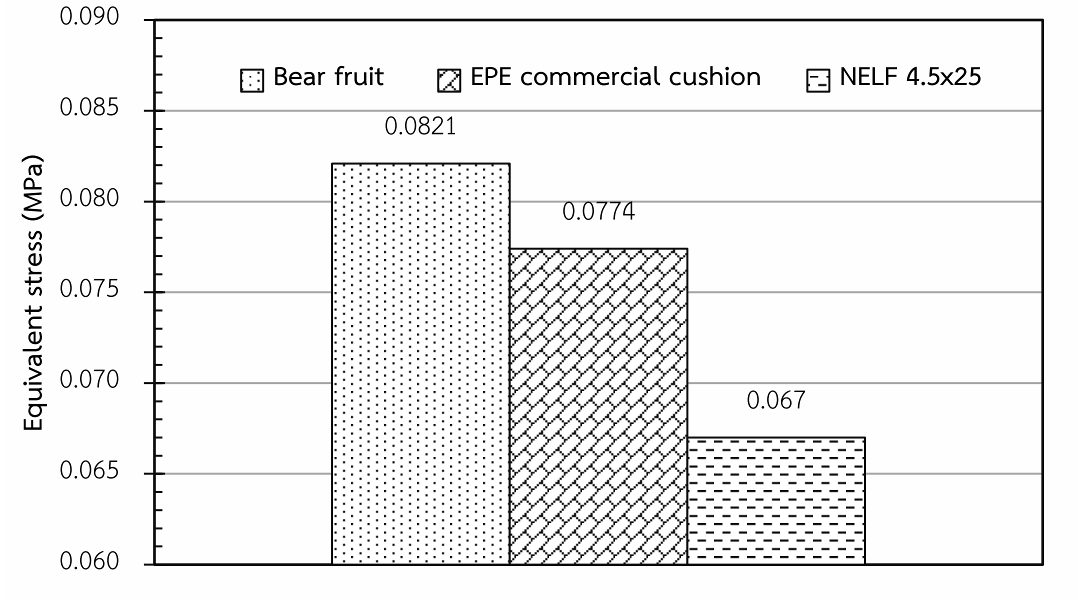


Figure 4.12 Maximum equivalent stress drop test 200 mm was observed at 0.013 s after impact of bear fruit and EPE.

This study investigated the maximum equivalent stress experienced by guava during a drop test from a height of 200 mm under three different packaging conditions: no packaging, EPE commercial cushion, and NELF 4.5×25. The results revealed that the unprotected guava (no packaging) exhibited the highest stress value at 0.0821 MPa. When cushioned with the EPE commercial material, the stress was reduced to 0.0774 MPa, representing a 5.72% decrease. Notably, the NELF 4.5×25 material demonstrated the most effective cushioning performance, lowering the stress to 0.0670 MPa, which corresponds to a reduction of approximately 18.39% compared to the unpackaged case.

4.4 Density Reduction Effects on Impact Protection

This study investigates strategies to optimize the weight of NRLF by reducing its density while maintaining cushioning performance. Two primary approaches are examined: increasing internal voids within the foam (densities of 420, 397, and 345 kg/m³) to decrease overall weight, and reducing the number of cushion filaments (25, 20, and 15 filaments) used in the material. The research aims to identify the optimal balance between minimizing weight and preserving cushioning effectiveness. A Glom Sali guava

(250 g) investigation at drop test 100 mm. is used as a model fruit representing spherical produce.

The drop test simulation results show that both the density of the cushion material (420, 397, and 345 kg/m³) and the number of filaments (25, 20, and 15) significantly influenced the maximum stress experienced by the guava upon impact.

Across all densities, it was observed that a reduction in filament number consistently led to an increase in maximum stress. For example, at a density of 420 kg/m³, the maximum stress values for 25, 20, and 15 filaments were approximately 0.0566 MPa, 0.0580 MPa, and 0.0635 MPa, respectively. This trend persisted for the other densities: at 397 kg/m³, the stress increased from 0.0578 MPa (25 filaments) to 0.0640 MPa (15 filaments); and at 345 kg/m³, the stress rose from 0.0594 MPa (25 filaments) to 0.0653 MPa (15 filaments).

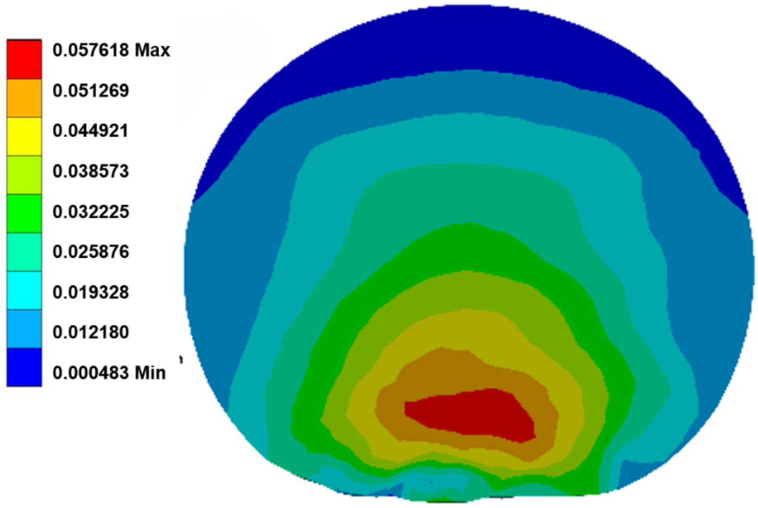
This pattern indicates that reducing the number of cushioning filaments diminishes the material's ability to absorb impact, regardless of density. Moreover, comparing across densities at the same filament count, lower density materials exhibited higher maximum stress. At 25 filaments, the maximum stress increased from 0.0566 MPa (420 kg/m³) to 0.0594 MPa (345 kg/m³), and a similar pattern was seen for filament numbers 20 and 15.

These results reflect the trade-off between weight reduction and cushioning performance. As both lower density and reduced filament count contribute to decreased material usage and lighter weight, they also compromise energy absorption capacity, leading to increased stress on the guava during impact.

The time of peak stress was observed at approximately 0.013 seconds after impact in all cases the result shown in Figure 4.22, which aligns with the expected moment of maximum deformation upon contact. This further confirms that the initial impact resistance is a critical factor in the effectiveness of the cushioning system.

filaments number 25.

(a)



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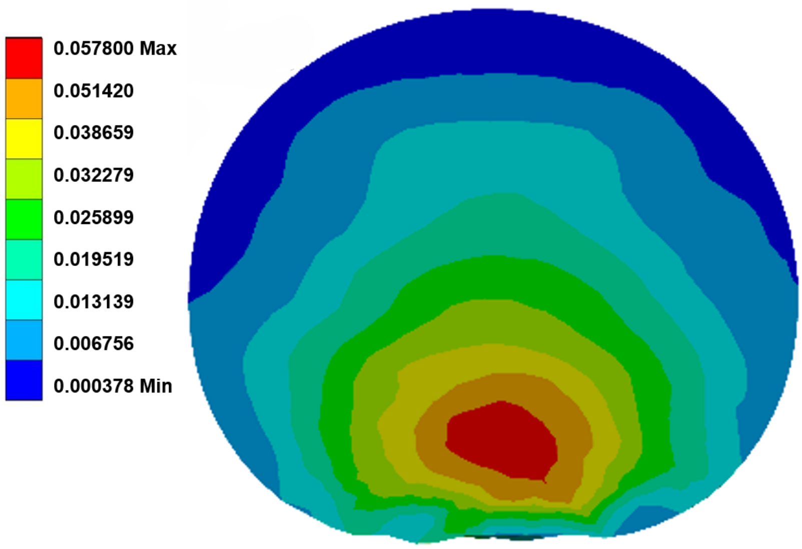


Figure 4.13 Stress [MPa] in the gravity direction for the drop height 100 mm filaments number 25 and the density (kg/m^3) (a) 420, and (b) 397from a cross-section view.

(c)

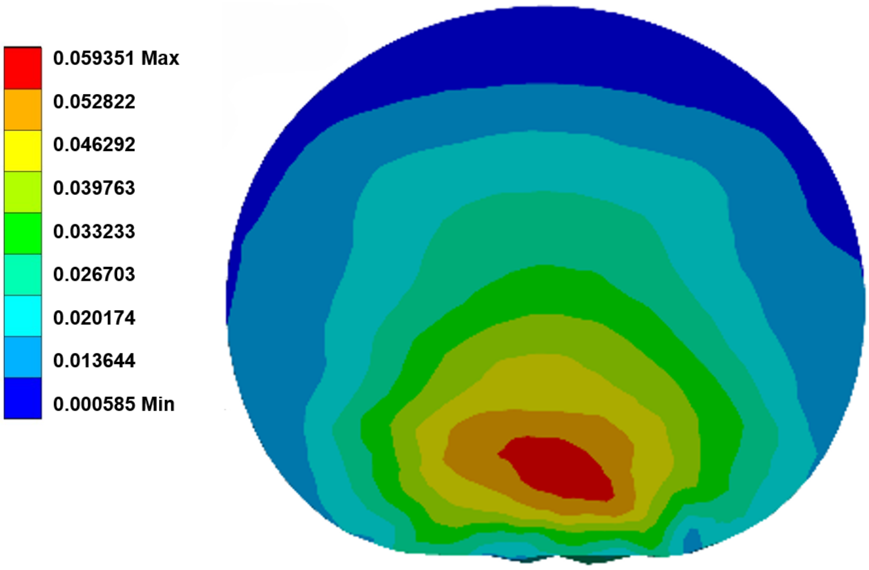


Figure 4.14 Stress [MPa] in the gravity direction for the drop height 100 mm filaments number 25 and the density (kg/m^3) (a) 420, (b) 397, and (c) 345 from a cross-section view.

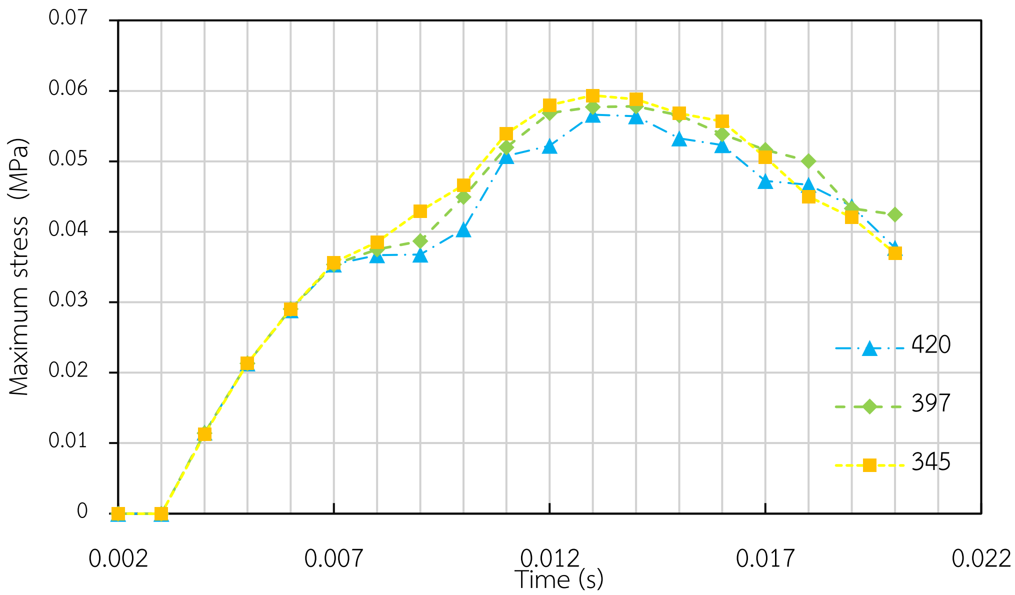
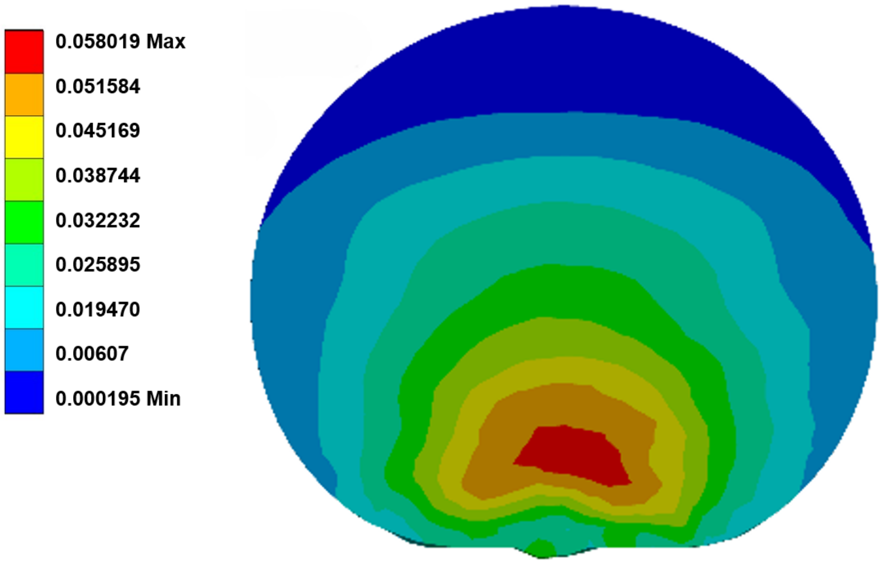


Figure 4.15 Plot Maximum stress (MPa) Time (s) plot for the model of filaments number 25 of and the density (kg/m^3) 420, 397, and 345.

filaments number 20.

(a)



(b)

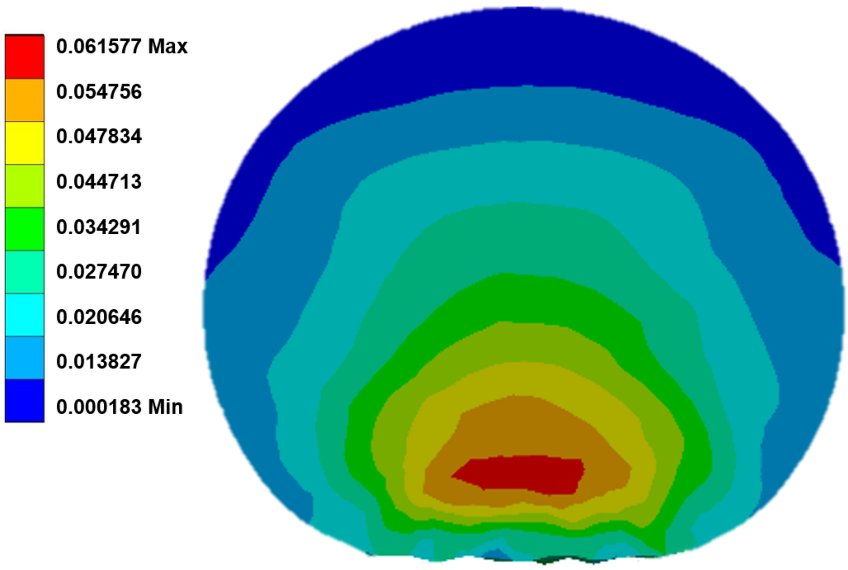


Figure 4.16 Stress in the gravity direction for the drop height 100 mm filaments number 20 and the density (kg/m^3) (a) 420, and (b) 397 from a cross-section view.

(c)

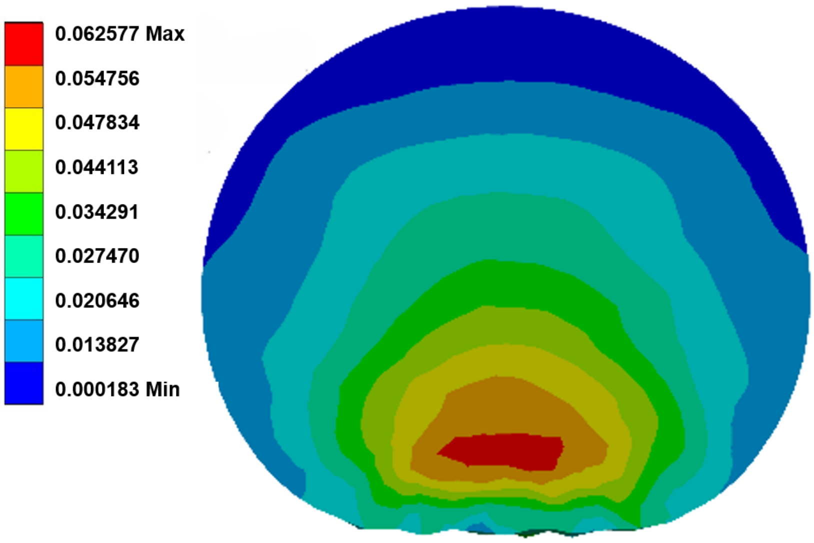


Figure 4.17 Stress in the gravity direction for the drop height 100 mm filaments number 20 and the density (kg/m^3) (a) 420, (b) 397, and (c) 345 from a cross-section view (Continued).

(d)

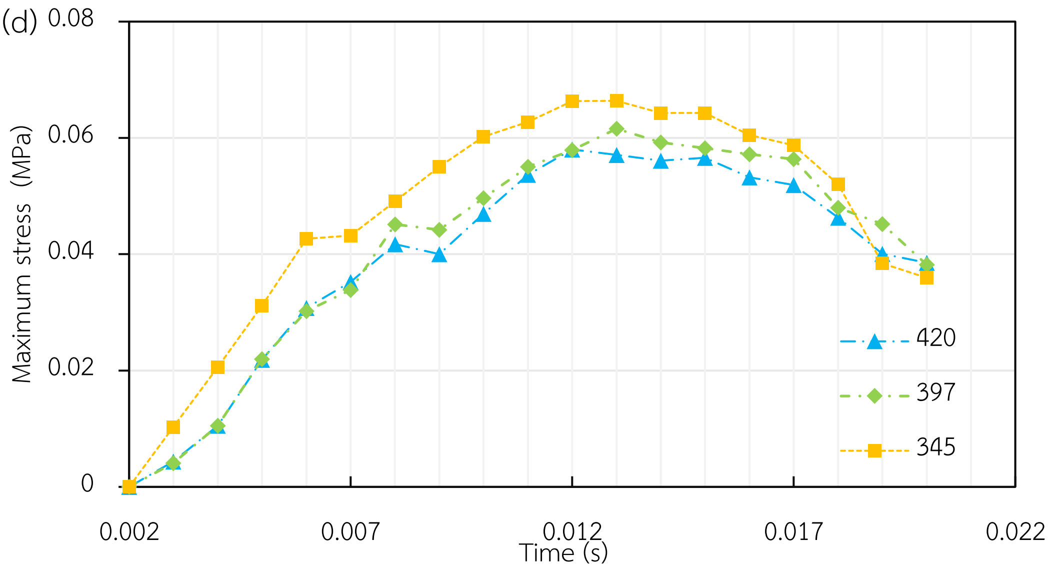
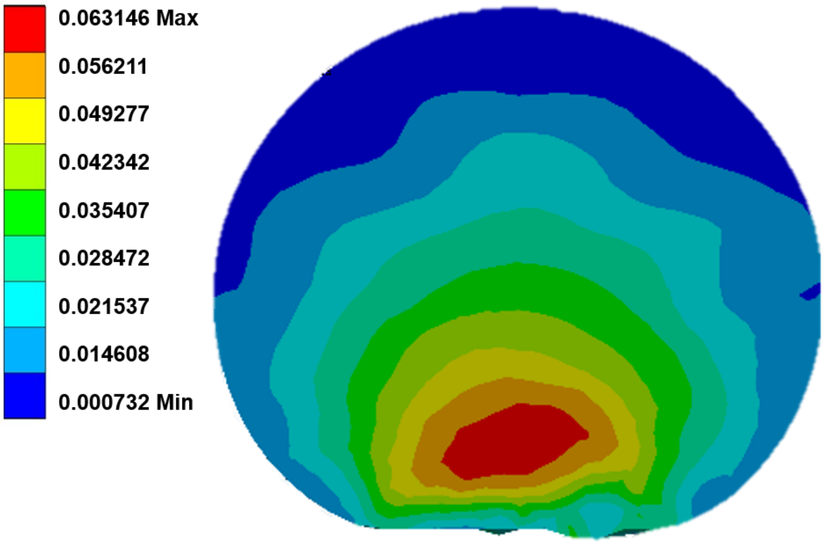


Figure 4.18 d) Maximum stress (MPa) Time (s) plot for the model of filaments number 20 of and the density (kg/m^3) 420, 397, and 345.

filaments number 15.

(a)



(b)

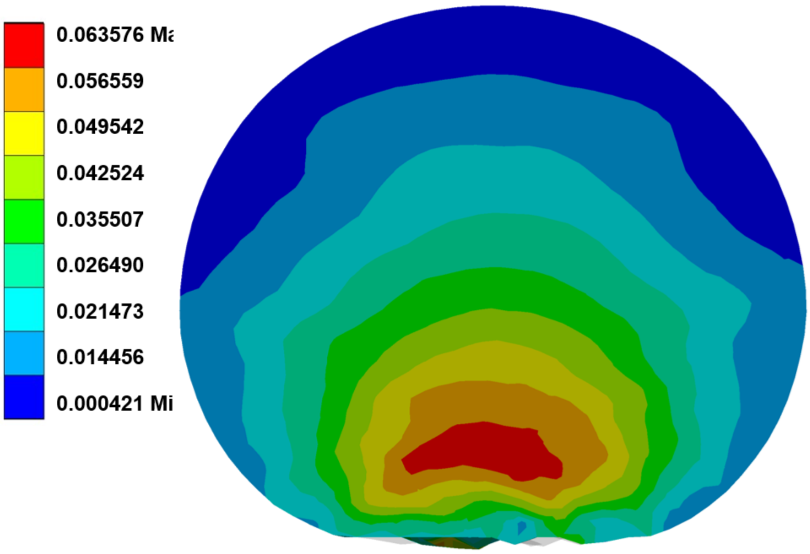


Figure 4.19 Stress [MPa] in the gravity direction for the drop height 100 mm filaments number 15 and the density (kg/m^3) a) 420, and b) 397 from a cross-section view

(c)

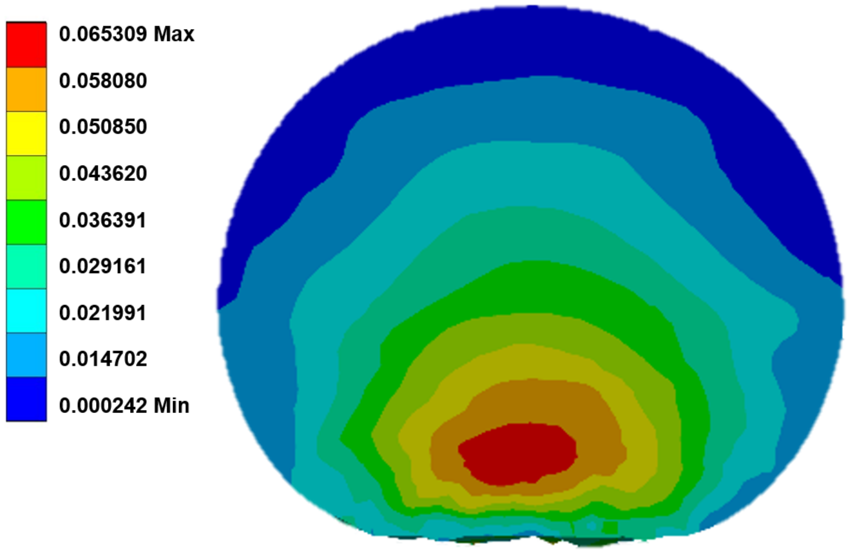


Figure 4.20 Stress [MPa] in the gravity direction for the drop height 100 mm filaments number 15 and the density (kg/m^3) c) 345 from a cross-section view (Continued).

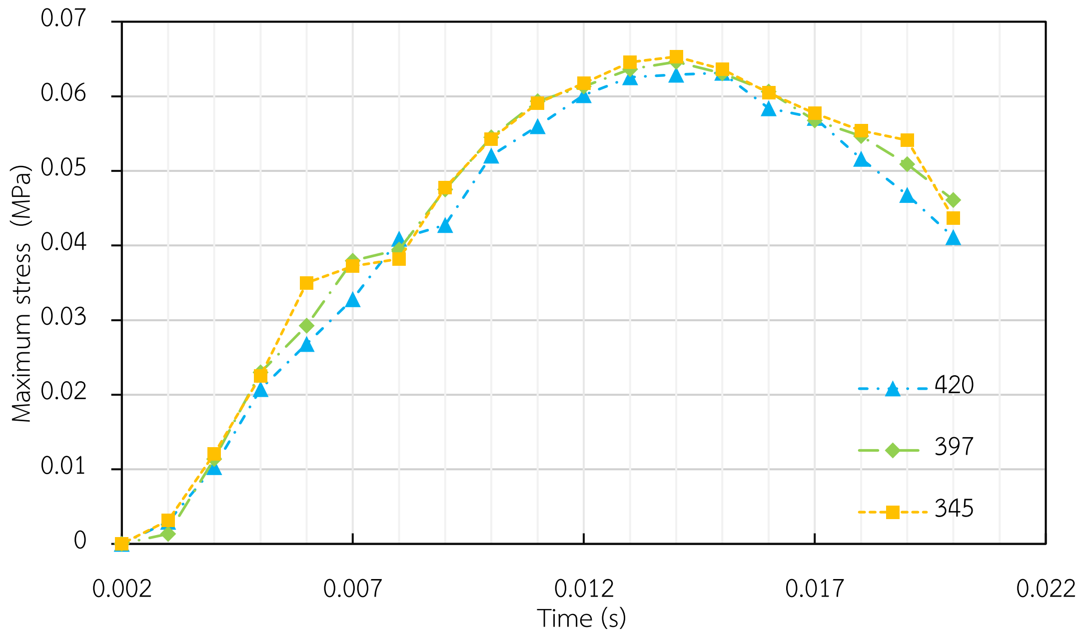


Figure 4.21 Maximum stress (MPa) Time (s) plot for the model of filaments number 15 of and the density (kg/m^3) 420, 397, and 345.

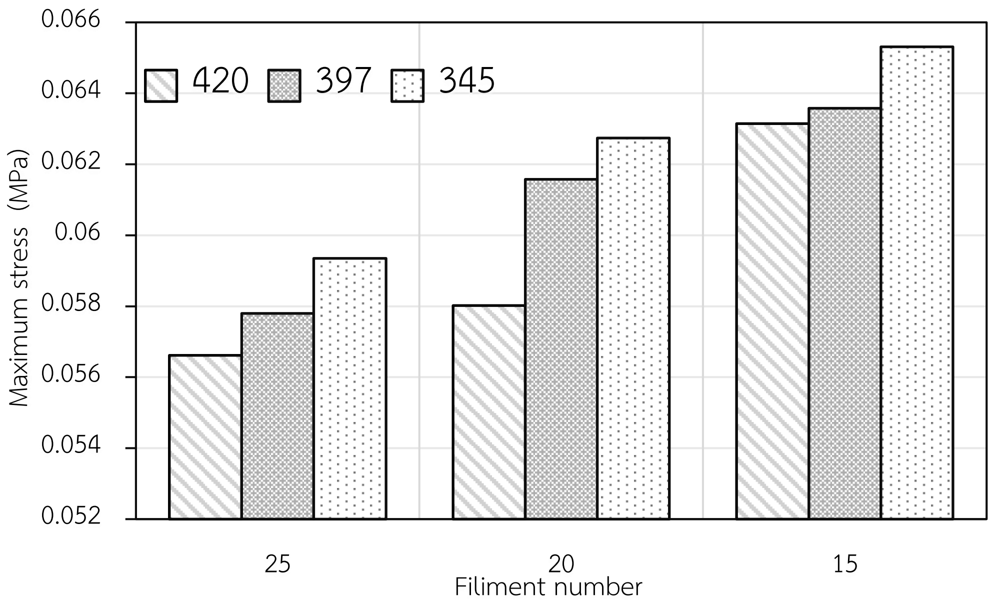


Figure 4.22 Maximum stress values for samples with filament numbers 15, 20, and 25, and densities of 420, 397, and 345 kg/m^3 drop test 100 mm was observed at 0.013 s after impact.

Filaments number	Density (kg/m^3)	Weight (grams)
25	420	20.0271
	397	18.972
	345	16.487
20	420	18.068
	397	17.078
	345	14.841
15	420	15.169
	397	14.338
	345	12.460

Tabel 4.1 Relationship between number of filaments, density, and weight